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ORIGINAL ARTICLES.

On some Effects of Wind and Sun in the Desert of Tumbez, North-West Peru.

By C. Barrington Brown, M.C., M.A., A.R.S.M., F.G.S.

(PLATES XIX AND XX.)

DR. T. O. BOSWORTH [1] has described some effects of wind and sun in producing topographical forms and in modifying the shapes of stones on the surface of the deserts of Tumbez and Paita. This paper describes certain forms of rocks and stone erosion, not mentioned in his work, from an area further north than that in which his more detailed observations were made.

The *Desierto de Tumbez* is a small part of that vast stretch of arid country which lies between latitude 3½ degrees south, near Tumbez, in the north of Peru, to latitude 30 degrees south at Coquimbo, in Chile, bordered on the west by the Pacific Ocean, and on the east by the Western Cordillera of the Andes. The most northern part of this rainless strip, the Tumbez desert, begins just south of the town of that name at the mouth of the Guayas River, and stretches southwards, in a belt 20 miles wide, between the ocean and the Amotape Mountains, as far as the River Chira. Cabo Blanco is a small headland in this belt 82 miles south-west of Tumbez, and is well known to navigators. Darwin mentions this point as being the northern limit of the desert region of the Pacific Coast, but this statement is only true if the distinction between the "Despoblado" (uninhabited region) and the "Desierto" (desert, but sparsely inhabited region) is maintained.

South of the Chira River, the Tumbez desert passed into the Despoblados of Puira and Paita, and, except for the port of Paita and villages on the Puira River, is almost uninhabited.

In the neighbourhood of Cabo Blanco, the great tableland, Tablazo de Mancora, at an elevation of 950 to 1,100 feet, forming the country inland to the Amotape Mountains, approaches to within one and a half miles of the sea, and thus gives rise to rugged, rock-strewn slopes down to the shore. This tableland, and the other, lower level, sea-floors of Pleistocene age, have been ably described by Dr. Bosworth.

[1] *Geology of the Tertiary and Quaternary Periods in the North-West Part of Peru*, by T. O. Bosworth, London, 1922.

I. Hollow Blocks.

On the slopes just mentioned, 2 to 3 miles north of Cabo Blanco, occur, scattered along the ridges between ravines, blocks of limestone of all sizes from a few cubic feet to 3,000 cubic feet or more in volume, to a greater or less degree hollowed out; so that in the best examples a mere shell remains.

Eocene clays and sandstones, considerably disturbed, form the country. Resting upon the upper surface of these, which is a plain of marine denudation now at an elevation of 750 feet, is a series of Pleistocene beds consisting of calcareous sands and pebble beds, with several harder beds of shelly limestone. The lowest important shelly limestone occurs about 80 feet above the base, and forms the outmost edge of the Tablazo as a vertical cliff 10 to 20 feet high. Masses of all sizes, under weathering, break away and fall down the slopes, and are found at all elevations down to sea-level. These are the blocks which undergo this particular form of weathering.

The action is as follows: During the early months of the year there occur very occasionally light showers of rain in the early morning. A slight solution of the surface of the block takes place. All trace of water is removed by the sun. In course of time the block acquires a more closely cemented shell. The wind, driving sand grains with it, attacks the block and perforates the shell. Thereafter disintegration of the softer interior is rapid, and with the formation of a cavity, eddies of driven sand quickly enlarge it until merely the outer crust of the block is left. Disintegration of this crust, of course, also proceeds, but more slowly. The shell is gradually etched out along bedding planes, and finally the block disappears into a heap of small fragments.

Figures 1 and 2 (Plate XIX) show two stages: the first figure a block almost perfectly hollow; the second figure another block in a later stage, where the crust is beginning to decay. The block is standing with its bedding planes vertical.

II. Sun-cracked Pebbles.

Besides the types of "sun-sliced", "sun-split", and exfoliated pebbles described by Dr. Bosworth, there is another variety, illustrated by Figures 3 and 4 (Plate XX). Both pebbles are of indurated sandstone of Carboniferous age. Such are now found on the surface of the Mancora Tablazo, near Cabo Blanco. They are derived from rocks of that age in the Amotape Mountains.

The heat of the sun has expanded the exposed side during the day; at sundown rapid radiation has caused contraction. Irregular cracks develop, but do not penetrate the pebble to the underside, which has a continuous surface.

In Fig. 3 the cracks have no relation to the bedding planes; in Fig. 4 there is one crack along a bedding plane combined with the others. The most noteworthy point, however, about this specimen is the curling outwards of a part of the crust.

Fig. 5 shows a series of parallel terminating cracks in an andesite pebble from the same locality. This is of the same type as the "sun-sliced" pebbles.

III. Wind-etching.

In the Tertiary clays occur lenses of calcareous claystones, red or yellow in colour. Fig. 6 shows wind-etching in the surface of a splintered fragment on all sides, but the reason why the sculpture has taken this form is obscure. Figs. 1 and 2, two views of another mudstone, show an advanced stage in erosion by wind-borne sand.

Note.—The fragment, Fig. 6, is from an outcrop of Eocene at Lobitos; that shown by Figs. 1 and 2 is from the Mancora Tablazo.

The Geology of the British Virgin Islands.

By K. W. Earle, M.Sc., F.G.S.

(PLATE XXI.)

Introductory.

As far as the writer is aware, no geological account of the British Virgin Islands has ever appeared in a British journal, the only two writers to give them anything more than passing attention being P. T. Cleve (1),[1] who visited most of the islands during an extended tour in the West Indies in 1868–9, and A. G. Hogbom (2), who investigated and described petrologically many of the igneous rocks collected by Cleve. In view of the extended operations of American geologists in the Greater Antilles in recent years, it may not, therefore, be without interest to give a brief description of the geology and petrology of the islands, as a preliminary guide to geologists who may be tempted to study the area in greater detail in the future.

The specimens and micro-slides illustrating the paper are housed at the British Museum (Natural History Museum).

I am indebted to Mr. W. Campbell Smith of the British Museum, who has looked through many of the micro-slides and given much valuable help both as to mineral determination and rock nomenclature, and to Dr. J. W. Evans, who has given much helpful advice and criticism of the original MS. of the paper.

Topographical.

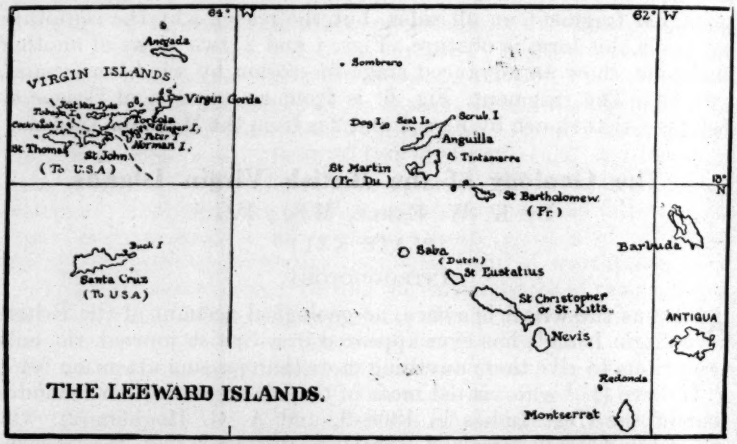
The British Virgin Islands, situated east of the American Islands of St. Thomas and St. John in lat. 18° 25′ N., long. 64° 30′ W., constitute the most northerly of the group under the Leeward Islands administration. They comprise in all more than fifty separate islands and rocks, which may be divided roughly into three groups running parallel to each other in a direction varying between E. and W. and N.E. and S.W.

The first group includes the island of Tortola, the largest of all the British Islands, with the adjoining islands at the east end

[1] Numbers refer to bibliography at the end of the paper.

of Great and Little Camanoe, Scrub I., Guano I., and Beef I., and at the west end Frenchman's Key and Great and Little Thatch Islands.

The second group lying north and west of Tortola comprises the islands of Jost Van Dyke, Little Jost Van Dyke, Tobago, and Little Tobago.



Key-Map showing the relation of the British Virgin Islands to the Leeward Islands Proper. All islands are British unless otherwise indicated.

The third group curves round in an arc to the south and east of the first group, and comprises the islands of Virgin Gorda (with the adjoining islets Necker I., Prickly Pear I., and Mosquito I.), Fallen Jerusalem, Round Rock, Ginger I., Cooper I., Salt I., Norman I., Dead Chest,[1] and Peter I.

The three Dogs form a connecting link between the first and third groups, while Anegada, the most remote of all the islands, and distant some 30 miles north of Virgin Gorda, forms a unit by itself. These main groups are separated from each other by deep channels never less than 14 or 15 fathoms in depth, the individual islands being also separated by deep channels and the whole group being separated from the Lesser Antilles by a submarine trough over two miles deep.

With the single exception of Anegada the islands are all hilly; the three largest ones might almost be called mountainous. Tortola itself, with an axial length of 10 miles, is composed of a long chain of hills throughout, uninterrupted by any transverse valley or pass, so that although the island is nowhere more than three miles wide it is impossible to cross from shore to shore without ascending nearly 1,200 ft. The culminating point of this range is Sage Mountain, 1,780 ft. high. The island is extremely rugged and largely

[1] Dead Chest or Dead Man's Chest, the island immortalized in R. L. Stevenson's *Treasure Island*.

covered by bush. Anegada, the second largest, has little connexion, owing to its isolated position, either geographically or geologically with the other islands. It consists entirely of a flat coral island thirteen square miles in area which has only been raised above the sea in recent times and nowhere exceeds 10–15 feet in altitude. Its surface is composed entirely of bare limestone rock with pockets of soil, in which low-growing scrub struggles to find a footing. The limestone is crowded with fossils, but all of recent species.

Virgin Gorda, the third largest island, rises to a central peak 1,370 ft. high, throwing off a lateral ridge to form a long narrow peninsula on the eastern side. The southern promontory is comparatively flat. Jost Van Dyke is a topographical and geological replica of Tortola. The remaining islands are all comparatively small and exceedingly difficult to explore, owing to their precipitous cliffs and the rugged, bush-covered nature of the interior; coral reefs are everywhere a menace to landing.

There are no permanently flowing rivers in the Presidency. There are no driving roads, communication being maintained on foot, on horseback, or by sea. Communication with the outside world is maintained by motor boat service to St. Thomas, while all inter-island journeys must be made by small sloop. Only seven of the islands are inhabited.

Geological.

The Virgin Islands and Puerto Rico, and to a certain extent also Cuba and Jamaica, form one geological unit, of which the British Virgin Islands, with the exception of Sombrero and Anegada, form the eastern extremity.

They are essentially a continuation and repetition of the American islands of St. John and St. Thomas, from which, with the exception of Jost Van Dyke and Great and Little Tobago, they are separated by channels less than a mile wide, but never less than 15–20 fathoms deep.

The general directions of the groups of keys is east and west, and is determined by the strike of the rocks in that direction.

These are entirely of an igneous and metamorphic nature, and include accumulations of pyroclastic rocks, volcanic breccias, and agglomerates. There are no signs anywhere of unaltered sedimentary rocks, and it is only by analogy with the neighbouring American islands and Jamaica that a reliable estimate of their age can be obtained.[1]

The igneous rocks are of all three types, plutonic, hypabyssal, and volcanic. The former consist essentially of diorites, granodiorites, and gabbros, the dyke rocks of pegmatites, felsites, hornblende-

[1] Cleve, *Ann. N.Y. Acad. Sci.*, vol. ii, mentions the occurrence of clay-slate with fossils resembling Silurian at Coxheath at the south-west end of Tortola, but no fossils were seen there by the present writer.

porphyrites, and dolerites, and the lavas of augite-andesites and basalts.

The metamorphic beds are of various types, and are undoubtedly for the most part metamorphosed sediments. They consist of hornblende-, quartz-, and mica-schists, phyllites and spotted schists, together with marbles, garnet-wollastonite rocks, granulites, and other types resulting from the alteration of impure limestones or lime-bearing sediments.

These rocks are often interbedded with the volcanic breccias and agglomerates, and it appears more than probable from the direction taken by the metamorphism that the sediments were originally largely of the nature of stratified tuffs.

There appears to be little change in the mineral character of the rocks over wide areas in which intrusive rocks are wanting (e.g. the centre of Tortola), and it is reasonable to suppose that the metamorphism has in large part been dynamic, perhaps accompanied by a general rise in temperature, rather than a contact metamorphism due to the intrusion of the diorites, etc. The effect of these dynamic agencies has been to lift the sedimentary beds bodily up on end into a highly inclined position without obliteration of the original stratification, but there is little evidence of intense crushing, faulting, or deformation of the beds such as is so characteristic of the metamorphic rocks forming the northern range of Trinidad.

These stratified metamorphic beds, which cover by far the larger part of the Presidency, invariably strike east and west, which fact is doubtless responsible for the alignment of the islands in that general direction. They always dip very steeply, varying from 45 to 90 degrees south and averaging about 70 degrees. Very fine examples of how the sea has taken advantage of this almost vertical bedding can be seen at Dead Chest and Ginger Island, where the Atlantic seaboards are constituted by one sheer bedding plane, nearly 200 feet high. Some idea of the enormous thickness of the sediments originally constituting this series may be gained from the fact that the width of outcrop of these steeply dipping metamorphic rocks, if uncomplicated by faulting, measures, from Peter Island to the north coast of Tortola, at least six miles.

Only in Necker Island, the most northerly island of all (Anegada alone excepted), do we at last seem to be getting beyond the zone of metamorphism. Here occur fine-grained blue-grey or yellow clays and tuffs and gritty conglomerates. At the north end of the island the dip is about 10 to 15 degrees north-west, while at the south end it is about the same, only in the opposite direction. That the area was not entirely beyond the influence of dynamic forces, however, is shown by local folding and contortion and the abundant occurrence in the tuffs of epidote nodules, which sometimes weather out on stalks like mushrooms in the more readily denuded clays, etc.; these epidote nodules may, however, be largely of the nature of bombs.

The only evidence so far adduced as to the age of these stratified

beds is that of Cleve (1), who records the finding of fossils in limestone nodules in the metamorphic series at Coki Point, St. Thomas. These are "in a very bad state, and sometimes silicified. The most common are *Nerineæ* and fragments of a large *Bulla* or *Actaeonella*. Besides these I have found an Ammonite, *Trochus*, *Pectunculus*, *Limopsis*, *Opis*, *Venus*, *Astarte*, *Corbula*. Some of them have a remarkable affinity to Cretaceous species, and I have no doubt that the rocks of St. Thomas and the other Virgin Islands are of Cretaceous age".

Associated and often interbedded with these stratified metamorphic rocks are pyroclastic rocks.[1] On the northern coasts of Tortola and Great Camanoe, and in Prickly Pear and Mosquito Islands this type of deposit occurs almost to the exclusion of others. In Cooper's Bay (Tortola) it varies from a fine breccia to a coarse volcanic agglomerate with included boulders of lava, etc., with a still dominant east and west strike. A curious feature of the finer tuffs is their tendency to spheroidal weathering, so that what appears to be a spheroidally weathered boulder of basalt turns out on cutting to be a fine hard tuff. At Cooper's Bay the conglomerates are cut by basic dykes of later age.

Whence came the foreign constituents of the deposit (i.e. the volcanic scoriae, lavas, etc., not derived by degradation of the sedimentary beds) is at present obscure. The widespread occurrence of the deposit in the neighbouring islands of St. Thomas and St. John points to the fact that there must have been somewhere in the area centres of volcanic eruption, though the highest points of Tortola show neither that absence of stratified rocks nor the topographic outline of the volcanic cones typical of the Lesser Antillean chain.

The plutonic rocks form bosses of comparatively small extent in the metamorphic series. There is evidence that they were not consolidated before the metamorphism took place, but that they were intruded through the already metamorphosed sediments. It is true that at times they show a "banding" of the ferromagnesian constituents when the rocks approach gneisses, but this was probably rather an original feature of the fluid magma than a structure subsequently induced by pressure. On the other hand, the diorite, wherever it is in contact with the metamorphic series, is seen not only to send veins into them, but to have caught up abundant "xenoliths" of the metamorphic rocks, resulting sometimes in a regular diorite-breccia. This must not be confused with a sort of "patchwork" diorite due to abnormal concentration of the basic or "heathen" parts of the magma.

Among the more unusual field characters presented by the plutonic rocks may be mentioned a beautiful example of orbicular diorite from near Colison Point, Virgin Gorda. From the same locality was collected a rock with radially crystallized nests of epidote, while garnet-epidote veins are also found in the diorite at Salt Island. This latter feature was also noted by Frazer (8) in Cuba. The

[1] Called "Blue Beache" by Cleve.

spheroidal weathering of the diorite by marine and atmospheric agencies is very characteristic in the field. Fallen Jerusalem, for instance, is composed of gigantic boulders, the size of cottages, piled together in all states of confusion, so that it is a physical impossibility to get round the island without ladders. Parts of the coasts of Beef Island and Virgin Gorda present the same phenomenon.

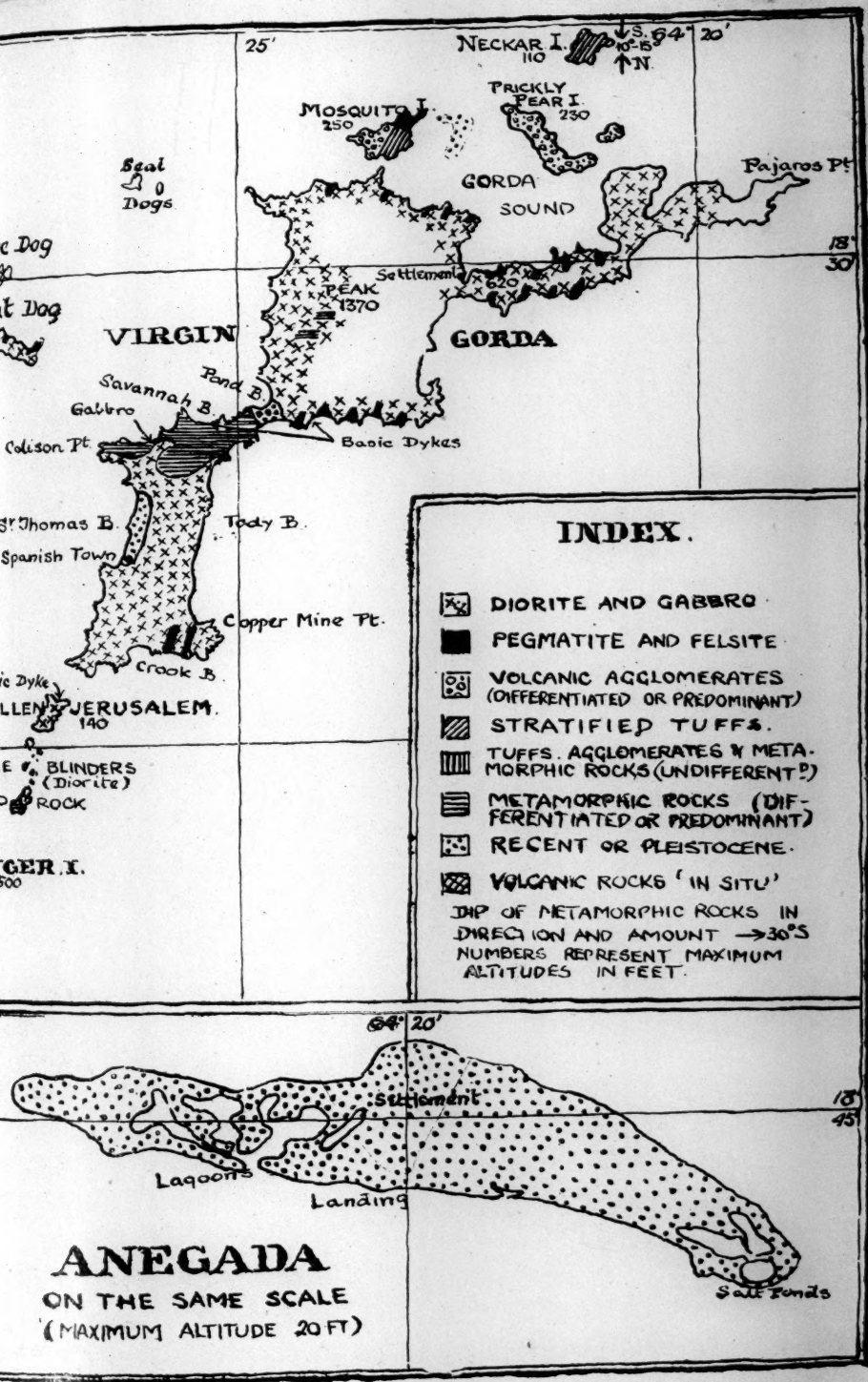
It is difficult to say exactly how far the diorite has been responsible for the various metamorphic rocks developed in the Presidency, but certain types found exclusively in the immediate neighbourhood of the intrusions are undoubtedly to be attributed to contact rather than to dynamic metamorphism. Among these must probably be placed the black amphibolites which sometimes show an extremely sharp and clear junction with the diorite. As they pass insensibly into slaty rocks and hornblende-schists, they probably represent the latter rocks thermally metamorphosed by the diorite. Other rocks undoubtedly due to the same cause are the garnet-epidote-wollastonite rocks and the garnet-bearing hornfelses found in close proximity to the intrusions at Cooper Island and Frenchman's Key, while the rotten recrystallized limestones approximating to marbles are probably of the same origin.

Large bosses of diorite occur at both ends of Tortola, on the western half of Beef Island, and the southern half of Virgin Gorda, while smaller patches are exposed in Ginger Island, Peter Island, Norman Island, Frenchman's Key, Thatch Island, The Dogs, Cooper Island, and Fallen Jerusalem.

The dyke rocks are of numerous kinds, and appear to be the last product of the igneous activity. Quartz veins and pegmatites not only radiate from the diorite through the schists (Belmont Point, Tortola, Salt Island, etc.), or are intruded along the planes of stratification (Belmont Point, Tortola), but sometimes even include fragments of the metamorphic beds (Cooper Island). In connexion with the quartz veins must be mentioned the very important ore deposits found and formerly worked at Copper Mine Point, Virgin Gorda. There is no room here for a full description and history of the mine, but the workings, abandoned in 1869 and now buried under surface debris, extended to a considerable depth and distance under the sea. The ores obtained consisted of chalcopyrite, malachite, native copper, haematite, pyrites, and lastly molybdenite, which was at that time rejected as valueless. Other pegmatite veins would probably prove ore-bearing if properly exploited; gold has not been detected, but small quantities of silver were identified by assay in one or two of them.

Rather perplexing are a group of rocks which, for want of a better name, we will continue to call "Felsites".[1] The microscopic characters of these rocks will be described later. In the field they are white or grey finely crystalline rocks with little needles of ferro-magnesian minerals. While they occur as dyke rocks cutting the

[1] Cleve's name.


25'
NECKAR I.
110
S. 64° 10'-15'
N.
20'
PRICKLY PEAR I.
230
MOSQUITO I.
250
Seal
Dogs
GORDA
SOUND
Pajaros Pt
18'
30'
Settlement
620
PEAK
1370
VIRGIN
GORDA
Savannah B.
Pond B.
Gabbro
Colison Pt.
Basic Dykes
St. Thomas B.
Tody B.
Spanish Town
Copper Mine Pt.
Crook B.
JERUSALEM.
140
BLINDERS
(Diorite)
ROCK
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DIORITE AND GABBRO
PEGMATITE AND FELSITE
VOLCANIC AGGLOMERATES (DIFFERENTIATED OR PREDOMINANT)
STRATIFIED TUFFS.
TUFFS. AGGLOMERATES & METAMORPHIC ROCKS (UNDIFFERENTD)
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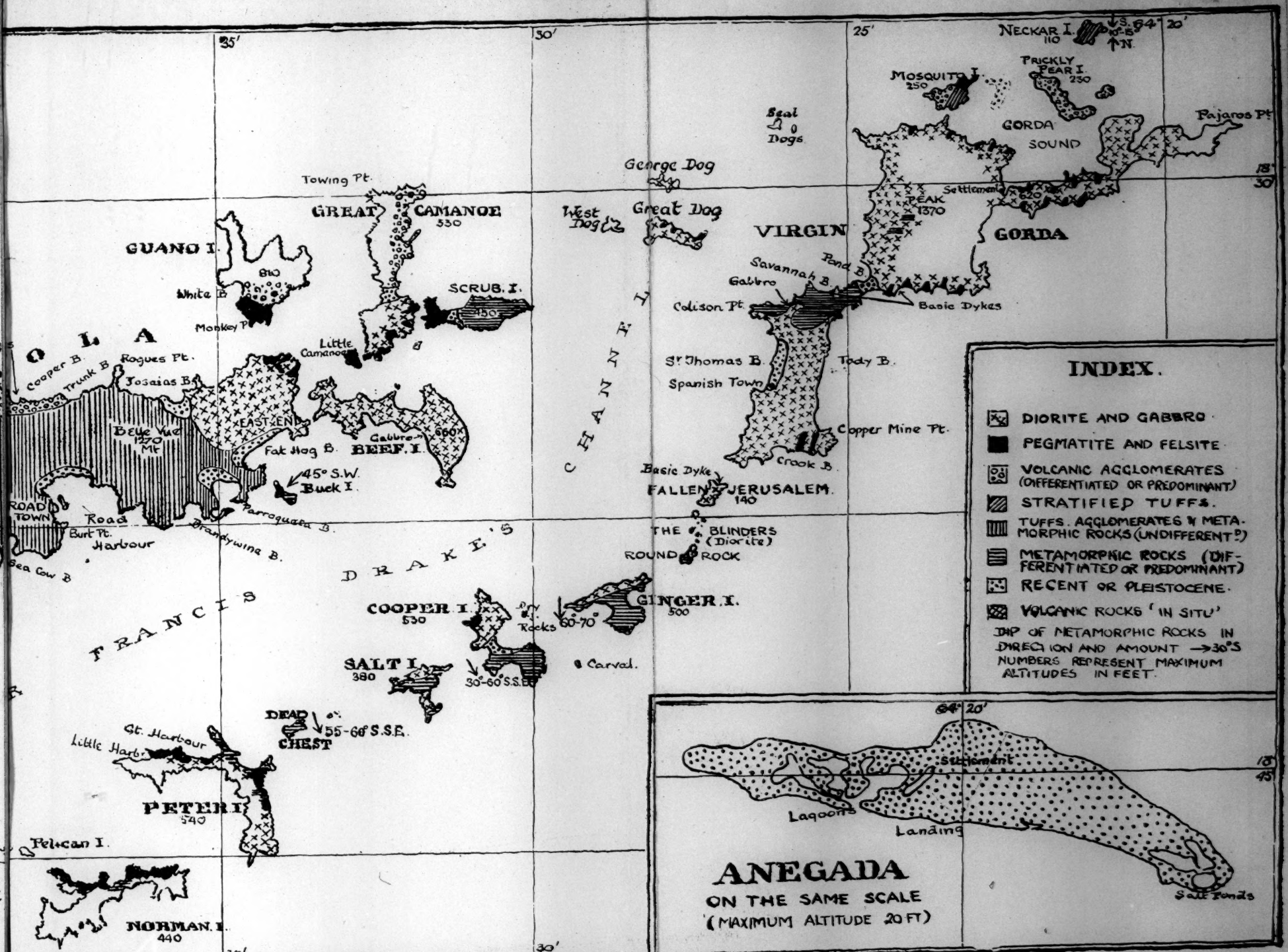
GEOLOGICAL SKETCH MAP
OF THE
BRITISH VIRGIN ISLANDS
BY
K.W. EARLE M.Sc. F.G.S.

N.B. GREAT AND LITTLE TOBAGO, TO THE WEST OF JOST VAN DYKE, ARE NOT SHOWN ON THIS MAP.

SCALE: APPROX. 2 MILES TO ONE INCH.


35'
30'
25'
20'
18'
30
NECKAR I. 110
S. 64° W.-15 N.
MOSQUITO I. 250
PRICKLY PEAR I. 230
Seal Dogs
GORDA SOUND
Pajaros Pt.
George Dog
Towing Pt.
GREAT CAMANOE 530
West Dog
Great Dog
VIRGIN GORDA
Settlement
PEAK 1370
620
Pond B.
Savannah B.
Gabbro
Basic Dykes
Colison Pt.
GUANO I.
810
White B.
Monkey Pt.
SCRUB I.
450
Little Camanoe
CHANNEL
St. Thomas B.
Tody B.
Spanish Town
Copper Mine Pt.
Crook B.
Cooper B.
Trunk B.
Rogues Pt.
Josias B.
EAST END
Belle Vue 1270 Mt.
Gabbro
660
Fat Hog B.
BEEF I.
45° S.W.
Buck I.
Basic Dyke
FALLEN JERUSALEM 140
ROAD TOWN
Road
Burt Pt.
Harbour
Parroquets B.
Brandywine B.
Sea Cow B.
THE BLINDERS (Diorite)
ROUND ROCK
FRANCIS DRAKE'S
COOPER I. 530
Rocks
60-70°
GINGER I. 500
SALT I. 380
30-60° S.S.E.
Carval.
DEAD CHEST
55-60° S.S.E.
St. Harbour
Little Harbr.
PETER I. 540
Pelican I.
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is sometimes present. I have not with certainty recognized hypersthene in my slides, which are not very numerous.

A rock from near Road Town, Tortola, consists of large twinned phenocrysts of labradorite in a groundmass of the same, without ferromagnesian minerals. The absence of olivine-bearing basalts from my collection does not prove that they do not occur.

The tuffs do not call for special description. Andesitic in character, they vary from fine ashes consisting of little angular fragments of quartz, felspar, augite, etc. (Necker Island and Prickly Pear Island), to brecciated rocks containing complete fragments of basaltic and andesitic rocks (Jost Van Dyke). Some of the tuffs are pyritous and even under the microscope display the spheroidal structure that is often so characteristic in the field.

Summary and Conclusions.

The geological structure of the British Virgin Islands correlates them indisputably with the Greater and not with the Lesser Antilles. The latter are composed essentially of Tertiary volcanic rocks of andesitic or basaltic type,[1] with or without development of sedimentary strata which, when present, only dip at gentle angles and never show the violent effects of such dynamic forces as have been responsible for the folding and "up-ending" of the strata in the Virgin Islands. The tremendous depth of the channel separating the British Virgin Islands from the Lesser Antilles has been ascribed to faulting, probably initiated in Pliocene times.

The work of Cleve (1), Hill (4), Vaughan (5), and others (6) in the American Virgin Islands, Porto Rico, the Dominican Republic, Cuba, Haiti, and Jamaica, indicates that the British Virgin Islands form geologically only the eastern termination of that main group of islands and have been subjected to the same earth movements as them. The evidence for attributing a Cretaceous age to the sedimentary series has already been referred to.

With regard to the age of the folding and igneous intrusion, Vaughan [2] considers that the folding took place between upper Eocene and middle Oligocene times, and that the intrusion of the diorites took place at approximately the same date. (7)

Wythe Cooke considers [3] that the igneous basal complex in the Dominican Republic certainly dates from Cretaceous time, but that part is probably older. He also considers that the stresses that folded and sheared these rocks were probably active during Eocene time or earlier, and that the intrusion of the great masses of dioritic rocks probably occurred before the deposition of the Eocene sediments.

According to Hill (4), however, "in mid-Tertiary times granitoid intrusions were pushed upward into the sediments of the Greater

[1] e.g. augite or hypersthene andesites, augite, hornblende, or olivine basalts, dacites, etc.

[2] Loc. cit., pp. 607, 609.

[3] Loc. cit., pp. 50, 79, 80.

Antilles, the Caribbean, Costa Rican, and Panamic regions." Frazer, on the other hand (8), considered the nuclear axis of Cuba and San Domingo, and possibly of all the Caribbean islands, to be Archaean, a view upheld also by Dr. W. Bergt. (9)

There is no doubt that the key to these problems lies in the larger islands of the Greater Antilles, for it is only there that unaltered fossiliferous sediments occur and can be studied in relation to the igneous intrusion and metamorphism. There appears, however, to the writer to be nothing either in the geological or faunal evidence necessarily indicating previous land connexion at any time between the Virgin Islands and the Lesser Antilles, and on this matter it is hoped to furnish further evidence at a later date.

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The Base of the Devonian.

(SUPPLEMENTARY NOTE.)

By Professor L. DUDLEY STAMP, B.A., D.Sc., A.K.C., F.G.S.

MY attention has recently been called to some very interesting comments on the problem of the delimitation of the Silurian and Devonian systems, which were made by Dr. Elles in her Presidential address to Section C of the British Association at Liverpool.[1] I am so heartily in agreement with all the principles of the modern classification of strata, as laid down by Dr. Elles, that it seems of advantage to recall very briefly how closely these principles are adhered to in using the Ludlow Bone-bed as the local base of the Devonian in England. Dr. Elles says :—

> It can hardly be doubted at the present day that the most efficient classification of strata is that based upon the palaeontological principle of the coming in of new forms, but, if the classification is to be of wide

[1] Elles, "Evolutional Palaeontology in relation to the Lower Palaeozoic Rocks": *Report Brit. Assoc. Liverpool*, 1923, pp. 83–107.

application and to be depended upon, this coming in of new forms must not be directly connected with changes in the character of the sedimentation. Physical causes which induce changes in the nature of the sediments are no doubt important, and probably give great impetus to evolutionary development, but to be depended upon they must be reflected in those faunas of the deeper parts of the epicontinental seas where sedimentation continues apparently unaltered; in other words where the change in the fauna shows primarily as an advance in the evolutional stage.

Accepting this great principle, my claim is that the faunal changes signalled by the curious and specialized physical changes indicated by the Ludlow Bone-bed *are* reflected in the deeper parts of the sea. I hasten to state my own firm conviction that the Downtonian of the British Isles *is* a facies formation, that the Downtonian fish-fauna *is* a facies fauna. Much research remains to be carried out on the Downtonian fishes, but at the present time it seems to me that the junction between the Downtonian and Dittonian, where the Downtonian fish fauna gives place to the fauna characterized by the more advanced *Pteraspis*, is the first true palaeontological or time-horizon which can be distinguished in British Devonian Rocks. By proving an unconformity below the Ludlow Bone-bed as one travels south-westward from the type localities in Shropshire, I have, I think, indicated sufficiently my conception of the Downtonian as a facies formation—we might almost say a sandstone and marl series basal to the Old Red Sandstone type of Devonian. In fixing the lower limit of the Devonian, apart from the important fact that the Ludlow Bone-bed satisfies conditions of priority, the final decision must rest upon correlation with an uninterrupted series of marine faunas. So far as I am aware, the only region in North-Western Europe where such a succession has been found and adequately studied is in Northern France (Liévin). In the summary of my detailed paper,[1] I definitely indicated that area as a standard of comparison for marine faunas. Previously, in my notes published in English, I have contented myself—in order to save space in these days of expensive printing—by quoting merely the *results* obtained in that area from the patient researches of the distinguished palaeontologists of the Lille School.[2] The succession at Liévin is as follows :—

Schistes et grès bigarrés de Vimy et de Pernes à *Pteraspis*.
Psammites de Liévin.
Schistes de Méricourt.
Couches de Drocourt.
Calcaire d'Angres.
Calcaire de Liévin.

The small fauna of the Liévin Limestone is incontestably Silurian. The succeeding Angres Limestone has forty-one species, including nine new. Of the Angres fauna, 80 per cent is strictly Silurian,

[1] Stamp, "The Base of the Devonian": GEOL. MAG., Vol. LX, 1923, p. 410 (Summary).

[2] Barrois, Pruvost, and Dubois, "Déscription de la Faune silurо-dévonienne de Liévin," 2me Fasc.: *Mem. Soc. Geol. Nord.*, vol. vi, ii, 1920 (1922).

including 21 per cent found in England in the Wenlock and Lower Ludlow only, but 45 per cent characteristic of the Upper Ludlow in this country. In the higher parts of the Angres Limestone there appear for the first time, and only then *very* rarely, four species belonging to undoubtedly Devonian genera. They are brachiopods: *Ambocoelia*, *Plethorhynchus*, *Proschizophoria*, and *Rensselaerina*. The representative of the latter genus is a new species.

In the succeeding Drocourt Beds sixty-three species are known, of which a dozen are special to the district. Of the fauna as a whole 55 per cent are undoubtedly Silurian, including a whole *Orthoceras* fauna characteristic of the E 2 stage of Bohemia or the Upper Ludlow of England, 8 per cent are common to Silurian and Devonian, 10 per cent are Devonian species, whilst 8 per cent are new species with Devonian affinities. Of the 10 per cent of Devonian species, unfortunately half are lamellibranchs—so neglected in England—leaving *Proschizophoria personata*, *Plethorhynchus dunensis*, and *Spirifer mercuri* as the only really characteristic Devonian forms present at this horizon.

When, however, we come to the Mericourt Beds there is a flood of new forms, characteristically Devonian. Of the fifty-five forms recorded a dozen are new, leaving forty-three to be considered. Of these eleven are Devonian and three of Devonian affinities, four common to the Silurian and Devonian, six peculiar to the Belgian Mondrepuits Beds, two (*Lingula cornea* and *Modiolopsis complanata*) characteristic of the Downtonian of England, leaving only seventeen Silurian species (eight of the English Upper Ludlow and eight of wide vertical distribution). The incoming Devonian forms including *Cryphaeus michelini*, *Homalonotus ornatus*,[1] *Orbiculoidea anomala*, *O. siegenensis*, *Proschizophoria personata*, *Spirifer mercuri*, *Plethorhynchus dunensis*, and *Haliserites dechenianus*. Moreover, the Devonian aspect of the fauna is still more marked by the numerical strength of the individuals of the Devonian species.

Adopting Dr. Elles's criteria for the determination of the base of a system, it seems incontestable that the great influx of Devonian forms with the Méricourt Beds *in the midst of the uninterrupted marine faunas* of Artois marks the base of the Devonian.

Directly this is admitted, the true position of the English Downtonian can be considered from a strictly palaeontological standpoint. The above figures have been quoted from Barrois, Pruvost, and Dubois' Memoir,[2] but I have personally examined all the specimens at Lille and wish to record my impressions of the striking similarity of the Angres and Drocourt faunas to the English Ludlovian and the almost equally striking foreign appearance of the

[1] In quoting such a genus as *Homalonotus*—found in Silurian and Devonian—it should be noted that evolutionary palaeontology is being considered. Note also the next four forms.

[2] pp. 175 to 183. Unfortunately care is needed in reading these pages, owing to the extraordinary large number of printer's errors amongst the figures.

application and to be depended upon, this coming in of new forms must not be directly connected with changes in the character of the sedimentation. Physical causes which induce changes in the nature of the sediments are no doubt important, and probably give great impetus to evolutionary development, but to be depended upon they must be reflected in those faunas of the deeper parts of the epicontinental seas where sedimentation continues apparently unaltered; in other words where the change in the fauna shows primarily as an advance in the evolutional stage.

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Méricourt fauna. The truly palaeontological argument for placing the English Downtonian at the base of the Devonian rests on the correlation of the Upper Ludlovian (*Chonetes* Beds) and the Drocourt Beds of Northern France. As I have indicated elsewhere,[1] all the most characteristic and commonest forms (except *Chonetes striatella*) of the Upper Ludlovian occur in the Drocourt Beds,[2] where they are also characteristic and common forms. The *Chonetes* Beds and Méricourt Beds cannot be correlated *because all the incoming Devonian forms in the latter are absent in the Chonetes Beds.* Further, the affinities between the *Chonetes* Beds and the Drocourt Beds are much closer than between the *Chonetes* and Angres Beds.

	Shropshire.	Character of faunas.	Northern France.
Devonian.	Dittonian.	*Pteraspis* Fish-fauna strictly comparable in both.	Pernes Sandstones, etc.
	Downtonian (higher).	*Cyathaspis* Fish-fauna comparable in both.	Liévin Psammites.
	Downtonian (lower).	*Thelodus* Fish-fauna (England). Marine fauna (France).	Méricourt Beds.
Silurian.	U. Ludlovian *Chonetes* Beds.	Marine fauna strictly comparable in both.	Drocourt Beds.
	U. Ludlovian.	Marine fauna strictly comparable in both.	Angres Limestone.
	Middle Ludlovian.	Marine fauna comparable in both.	Liévin Limestone.

When the lower Downtonian Beds of England are compared with the Méricourt Beds of Northern France, the following striking points are brought out:—

(1) The Silurian survivors are the same in both cases.

(2) Such marine or semi-marine forms as are special or very common in the lower Downtonian tend to be equally common in the Méricourt Beds (*Lingula cornea*, *Modiolopsis complanata*, and *Bellerophon trilobatus*).

(3) The incoming marine Devonian forms of the Méricourt Beds are replaced in England by the incoming Downtonian fish-forms—a difference admittedly due to the facies character of the English Downtonian. In the higher beds at Liévin, we come on to the

[1] Stamp, "Les faunes des couches de passage du Silurien au Dévonien en Angleterre": *Ann. Soc. Geol. Nord.*, vol. xlviii, 1923, pp. 18–29.

[2] This correlation is not invalidated by what I have said elsewhere about due consideration of geographical factors. The similarity of sediments indicates comparable physical conditions and the areas compared were probably not widely separated geographically.

Old Red Sandstone type. It is noteworthy, however, that the Liévin Psammites do *not* contain the simpler fish-forms of our *lowest* Downtonian, but the more complex forms such as *Cyathaspis* and a form so near the true *Pteraspis* that it has been named *Pt. gosseleti* by Leriche. Lithologically the Liévin Psammites match the Downton Sandstones; two facies-fossils occur to bear out the comparison (*Lingula minima* and *Modiolopsis complanata*), but the weight of palaeontological evidence correlates the Liévin Psammites with the *higher* Downtonian. The beds immediately following (Pernes Mottled Sandstones) have all the fish-forms characteristic of the Dittonian (*Pteraspis rostrata, Pt. crouchii*, and *Cephalaspis lyelli*).

Such is the palaeontological argument for placing the Downtonian in the Devonian system. The other arguments have already been considered in detail in the GEOLOGICAL MAGAZINE.

The Species-Concept in Palaeontology.

By A. E. TRUEMAN, D.Sc., F.G.S., University College of Swansea.

DURING recent years the nature of species has been frequently discussed by biologists, or, at least, by students of recent animals and plants, but much less attention has been paid to the subject by palaeontologists. Nevertheless, in palaeontology, as in neontology, as animals and plants are subjected to a more intensive study it is becoming increasingly difficult to make the concept of species fit the facts of nature. It has frequently been demonstrated that our knowledge of living forms is inadequately expressed by specific and generic names;[1] in the classification of fossils the problems are of different character and are more difficult of solution, because:—

1. A fossil usually represents a part—often a small part—of the living animal or plant.

2. The forms to be classified often include successive members of each line of descent, not merely terminals of diverse lines.

The writer suggests that the binomial or Linnean system of nomenclature, already strained in its application to recent forms, is proving inadequate for the needs of palaeontology.[2]

The writer shares with numerous palaeontologists the view that it is desirable that the species question and the problem of palaeontological nomenclature should be carefully considered. The aim of the present paper is to draw attention to some aspects of the

[1] See, for example, G. C. Robson, "A Note on Species as a Gene-complex": *Ann. Mag. Nat. Hist.*, (9) xi, 1923, p. 111.

[2] This was suggested by Déperet in 1909 (*Transformations of the Animal World*, p. 191). A distinguished palaeontologist, in a letter to the writer, suggests that the difficulty arises from the attempt to put palaeontological wine into neontological bottles! It may be suggested that, in general, a "species" in palaeontology is more comprehensive than a species in neontology.

problem ; it is too early to hope for a solution, but the following suggestions may afford a basis for future discussion :—

1. Any natural classification must be based as far as practicable on genetic affinity.

2. A palaeontological classification must be of such a character that a name or symbol is available to designate every recognizable form which characterizes a distinct horizon. Terminology must keep pace with the increase in stratigraphical knowledge.

3. It is in many respects better to have too many names (or symbols) than too few. In the words of Hyatt, " there is nothing to be dreaded in new names except to those who strive to get the animal kingdom by heart " ; nevertheless, a co-ordinated system of symbols may convey more readily intelligible ideas of fossils, and may be more easily memorized, than an equal number of unrelated names. The better-known specific names may always be used in their non-restricted sense, provided it is made clear that they are so used.[1]

Species in its Relation to Lineage.

I.

It will probably be most convenient in explaining some aspects of the problem to consider first the simple case in which a species may be taken as an arbitrary point in a lineage or line of descent.

In its simplest conception, a lineage is often considered as being represented at any one time by individuals which are identical except for unimportant and negligible variations. These individuals differ from those of other dates to an extent which depends partly on the rate of evolution, the changes manifesting themselves in one or more progressive characters. Although it will presently be necessary to suggest a modification of this view, this conception of lineage may be taken as approximately true for certain groups.

Most students of invertebrate palaeontology now believe that the successive stages of a lineage are not sharply marked off from one another. It is, therefore, theoretically impossible to separate the members of a lineage into three or four " species ", and as knowledge of certain groups of invertebrate fossils advances, this difficulty in classification is being increasingly felt. The successive stages of slowly-evolving lineages are on the whole likely to be more fully known than those of more rapidly evolving groups, in which, owing to interrupted sedimentation, only occasional stages may be found in any one area ; the nomenclature of members of the slowly evolving lineages will therefore present greatest difficulty at the present time.

II.

The problem is more complicated, however, when, as often appears to be the case, the lineage is represented at *each* horizon by forms which exhibit different degrees of acceleration in their progressive characters. Such variation in the members of a lineage

[1] G. W. Lamplugh, " On the Junction of Gault and Lower Greensand " : *Q.J.G.S.*, lxxviii, 1922, p. 1, note.

at one horizon has been described by Carruthers in simple corals,[1] by Hickling in certain gastropods,[2] and by the author in various lamellibranchs from the Coal Measures and the Lias.[3] The solution of the species-problem will be helped by studies in the variation of invertebrates, such as those that are being made by Alkins.[4] The wider study of variation in fossils made by Klahn [5] is of little value to the present discussion since the variation was not studied in relation to the evolutional tendencies of the several groups dealt with.

The case of the lineage of *Gryphaea incurva* from the Lower Lias will perhaps afford an adequate example of the nature of the problem. This group shows progression in several characters, of which the following may be taken for our present purpose :—

(*a*) Increase in coiling, from flat oyster-like shells to incurved *Gryphaea*.

(*b*) Production of a sulcus on the curved valve ; this commences late in life in forms like *Ostraea irregularis*, and appears at progressively earlier stages in the more incurved forms of the lineage.

Considering first the degree of coiling, it has been shown that not only are various stages in this progressive character found at successive horizons, but they are found actually in the same bed.[6] If a large collection is made from one horizon and the variation in this character is studied statistically, it is found that the specimens constitute a homogeneous group ; according to some writers, they must therefore be considered as one species.[7] But since they include forms identical with those on lower and higher horizons which can scarcely be called by another name, simply because of difference in age, the whole lineage is incapable of subdivision, for no divisions that may be made either in the specimens at one horizon or in those of successive horizons, have any objective reality.

A similar conclusion would be reached if variation in another unit character (bio-character) were studied. But these characters (*a* and *b* above) are largely, if not wholly, independent of one another ; although, naturally, the most sulcate specimens are generally the most incurved, these two characters are not closely linked, and it is

[1] R. G. Carruthers, "The Evolution of *Zaphrentis delanouei*" : *Q.J.G.S.*, lxvi, 1910, p. 523.

[2] G. Hickling, "The Variation of *Planorbis multiformis*" : *Manchester Memoirs*, lvii, 1913, p. 1.

[3] A. E. Trueman, "The Use of Gryphaea in the Correlation of the Lower Lias" : GEOL. MAG., LIX, 1922, p. 256.

[4] W. E. Alkins, "Morphogenesis of Brachiopoda" : *Manchester Memoirs*, lxvii, 1923, p. 1.

[5] Hans Klahn, "Der Wert der Variationsstatistik für die Paläontologie" : *Berichte d. Nat. Gesellsch. z. Freiburg*, 1920, p. 1.

[6] It must, of course, be remembered, as Mr. S. S. Buckman has repeatedly urged, that the finding of specimens in one block of stone is not necessarily proof of contemporaneity, but in the above instance the variation curves show that at each horizon the group is homogeneous ; this would be unlikely if the group included derived specimens of various dates.

[7] Hickling, op. cit., pp. 4, 19.

not uncommon to have a closely-coiled shell with no sulcus, or a shell like *Gryphaea dumortieri* with sulcus appearing very early.

The case may perhaps be more clearly stated by calling the stages of one progressive character (bioseries) A, and numbering the stages of incurving from 1 to 100 ; similarly the stages of progressive acceleration of sulcus development (B) may be numbered 1 to 100.[1] Now, at any horizon there is considerable variation in each of these characters ; thus forms with A 70, A 71, A 72, to A 84, for example, may be found together, with perhaps A 78 most abundantly. At the same horizon the variation in B may likewise range from B 70 to B 84. But while individuals such as (A 70, B 70) and (A 75, B 75) may occur, different individuals will present various combinations of stages in the two series, including perhaps (A 70, B 71), (A 84, B 70), (A 70, B 82), (A 73, B 80), etc.

Since these various forms co-existed, the writer would suggest that they were able freely to interbreed. For if the majority of co-existing individuals were not able to interbreed, and such a form as (A 70, B 70) were only fertile with (A 70, B 70), then it is necessary to suppose that innumerable parallel lines of evolution progressed side by side. It appears much more reasonable to suppose broader limits of interfertility, and although restrictive fertility may have operated between the extremes, this renders it still more difficult to decide the limits of species. The writer would suggest that some of the related " species " accepted by palaeontologists were able to interbreed, as, for instance, *Gryphaea obliquata* and *G. incurva*.[2]

If this interpretation of the relation of such forms is correct, however, it follows that the use of the term lineage needs some consideration. It is obvious that the usual conception of lineage, as a *line* of evolution, does not apply in these cases. For instance, the parents of (A 75, B 75) would not necessarily both be (A 75, B, 75) or the earlier (A 74, B 74), but might be (A 75, B 80) and (A 80, B 75), or (A 80, B 70) and (A 70, B 80). It is uncertain whether or not these biocharacters behaved as Mendelian units,[3] but it is clear that a line of evolution, from A 70, A 71, A 72, to A 80, could only be traced with difficulty, and that by crossing of parents representing various stages in the bioseries the " line " of evolution was considerably tangled. In fact, the " lineage " is rather a bundle of lines, or more correctly, a *plexus* of lines which repeatedly branch and re-unite. In such a lineage there is a definite trend in the progressive characters, but also considerable variation in those characters at each horizon.[4] It appears that a new name is required in place of " lineage " in such cases.

[1] This method of expressing the problem is adopted from H. H. Swinnerton, *Outlines of Palaeontology*, 1923, p. 391.

[2] Nevertheless, the " species " of the palaeontologist is *generally* much broader than that of the neontologist.

[3] H. H. Swinnerton, " The Use of Graphs in Palaeontology " : GEOL. MAG., LVIII, 1921, pp. 406–8.

[4] A somewhat similar conception is suggested by W. D. Lang, *Proc. Geol. Assoc.*, xxxiv, 1923, p. 132.

III.

If the relations of the various members of such gentes [1] or species-groups are correctly interpreted in the foregoing section, it is obvious that the ultimate classification of these forms is an intricate problem. Clearly the difficulties will be greatest in those lines of development which progress relatively slowly and have wide variation in the progressive characters at each horizon; for in such groups our knowledge of the lineage will usually be more complete than in quickly evolving groups which are more likely to be represented by isolated forms owing to discontinuous sedimentation and other causes.

There are obviously two ways in which a specific name may be employed, viz. :—

(1) For those specimens which agree with the holotype in every character they exhibit.

(2) For those more numerous specimens which, while differing from the holotype in certain characters, yet approximate more closely to it than to any other named form.[2]

In the former case a species, in an extreme instance, may include only one specimen, the holotype, and other names or symbols are needed to denote the related variants. In the second case, while the species has wider limits, there is nevertheless a necessity for names or symbols to denote the variants within the species; in other words, there is in either case a need of additional names or symbols if the mutations are to be used in correlation.

The writer is in favour of restricting the use of the specific name to specimens identical with the holotype; forms resembling or apparently related to the holotype (i.e. members of the species-group) may be indicated as at present by prefacing the specific name with *cf.* or *aff.* in the respective cases. It may be urged, however, that the Linnean system of binomial nomenclature is in many cases inadequate for the needs of palaeontology. Adherence to this system must lead to enormous increases in the numbers of specific names.

Species in Neontology

It is perhaps unnecessary to discuss fully here the relations of the species-concept in palaeontology and neontology, but a brief reference to some of the recent conclusions of biologists may help in the present discussion.[3]

[1] A. Vaughan, "The Palaeontological Sequence in the Bristol Area": *Q.J.G.S.*, lxi, 1905, p. 183.

[2] Compare W. D. Lang, *Catalogue of Cretaceous Bryozoa* (*British Museum*), iii, 1921, p. ii.

[3] Useful summaries of some of these conclusions will be found in the following: G. C. Robson, op. jam. cit.; B. M. Davis, "Species, Pure and Impure": *Science*, 1922, p. 107; G. H. Shull, R. A. Harper, and others, "The Species Concept, etc.": *Amer. Journ. Botany*, x, 1923, p. 221; N. I. Vavilov, "The Law of Homologous Series in Variation": *Journ. Genetics*, xii, 1922, p. 47.

As a result of plant and animal breeding experiments it has been shown that a pure species, consisting of individuals of the same hereditary composition, is almost an abstraction. Apparently nearly all species known to zoologists and botanists are hybrid in genetical constitution, yet in nature they breed true or nearly true to type. Selective breeding may isolate from each impure species an immense number of hereditarily distinct forms which some writers call "Jordanons", calling the broader Linnean species "Linneons".

At first sight it appears that this conception of impure Linnean species accords with the conception the writer has drawn attention to in the case of *Gryphaea incurva* and its allies. In this and other examples, an apparently homogeneous group may be regarded as an impure species, a group of more or less freely interbreeding individuals with interwoven pedigrees. In the same way it may be noted that the line of evolution of many modern species must be thought of as a plexus rather than as a single lineage.

Nevertheless, one important distinction must be made; for whereas Jordanons generally differ from one another in sharply contrasted characters, such as the presence or absence of some feature, the various members of such groups as the palaeontologist is concerned with merge into one another by imperceptible gradations.

In conclusion, the writer desires to express his indebtedness to numerous friends for frank discussion of these problems; he has received help from his colleagues, Dr. F. A. Mockeridge and Miss E. M. Rees, and from Mr. S. S. Buckman, Professor H. L. Hawkins, Professor G. Hickling, Dr. W. D. Lang, and Professor H. H. Swinnerton. Although valuable criticism and suggestions have been received from these workers, they do not necessarily share the views expressed in the paper.

Observations on the Micropetrology of South Wales Anthracite.

By Alan Stuart, M.Sc., University College of Swansea.

THE constitution and origin of anthracite has long been a question of absorbing interest, but until very recently the theories which were brought forward dealing with this subject, owing largely to the insurmountable difficulty of preparing thin slices upon which micropetrological work could be done, have lacked substantial evidence either to support or refute them. Lately, however, a new method which will materially widen our knowledge and advance research on the anthracite problem has been evolved.

Almost simultaneously H. G. Turner and H. R. Randall [1] in America and Mr. C. A. Seyler [2] in this country published accounts

[1] H. G. Turner and H. R. Randall (1923), "A preliminary report on the microscopy of anthracite coal": *Journal of Geology*, vol. xxxi, p. 306.

[2] C. A. Seyler (1923), "The microstructure and banded constituents of anthracite": *Fuel*, August, 1923, p. 217.

of having achieved results in the micropetrology of anthracite by etching polished surfaces. The American investigators, with anthracite from the Northern, Western Middle, and Southern Pennsylvanian Coalfields, used the following method with success. Blocks of coal were cut about 2 cm. side and two faces, one parallel to the bedding and one at right angles to it, were polished on an iron lap with medium carborundum powder and water, and then on glass with one minute tripoli powder. A final polish was given by rubbing on a novaculite honestone with a thick paste of rouge and water. The blocks were dried in an oven for an hour at a temperature of about 220 degrees centigrade, the faces being then brought to a red heat by means of the oxidizing blowpipe flame. With vertical illumination the structures can be seen to stand out in relief owing to the differential oxidation produced by the flame. The conclusions of Turner and Randall may be summarized here. All varieties of Pennsylvanian anthracite are found to be " composed of laminae of different lustre, texture and thickness ". Three varieties are recognized, viz. (*a*) brilliant jet-black layers, (*b*) glossy grey bands, and (*c*) dull lenticles resembling charcoal; (*a*) showing no structure or a preponderance of woody tissue, (*b*) spore exines, apparent vascular bundles, wood fibre, etc., and (*c*) wood fibre and wood cells sometimes crushed. The anthracite therefore in the main shows the same micro characters and the same plant structures as does bituminous coal. It is also noted that the organisms preserved show no more signs of crushing then do those of bituminous coal.

Mr. C. A. Seyler, working on a piece of dull anthracite coal and using a different etching process—that of Winter,[1] by which the polished surface is etched with hot dilute Schulze's solution—concluded that " the microscopic characters of the banded constituents of bituminous coal are shown to persist even into the anthracite region ".

It was thought that an examination of some Welsh anthracite would be interesting and Mr. D. F. Davies, F.G.S., kindly supplied specimens from the Big, Stanllyd, Charcoal, Green, Gras, and Pumpquart veins from the New Cross Hands Colliery.

Macroscopic Characters of South Wales Anthracite.

Macroscopically all the specimens examined could be divided by their lustre into three constituents, viz. (*a*) Bright black bands with splendent lustre and conchoidal fracture, (*b*) black bands of fairly bright coal with waxy lustre, and (*c*) dull black charcoal bands which occasionally develop a silky lustre. These three constituents are found in lenticles of various sizes arranged parallel to the bedding except the charcoal bands which sometimes occur in thin leaves crossing the bedding at about 45 degrees. The proportions of (*a*), (*b*), and (*c*) vary in different specimens, but no exact quantitative determinations have yet been made. Samples from the Big vein

[1] *Fuel*, 1923, p. 78.

showed a great preponderance of bright splendent coal, the charcoal bands appearing in thin leaves along the bedding planes and at high angles across it. Specimens taken from the Pumpquart vein also showed a large proportion of the jetty bright coal with conchoidal fracture. In all the other specimens the proportion of (*a*) to (*b*) was about equal with a relatively small amount of charcoal, although the widths of the bands in each seam varied considerably from microscopic proportions to a few centimetres across the bands.

Microscopic Structure of South Wales Anthracite.

One of the methods used by Randall and Turner was found to give good results with Welsh anthracite. Specimens with faces parallel and normal to the bedding were taken and surfaces up to 12 sq. cm. were polished on plate glass with successively finer grades of carborundum powder, smoothed on a fine honestone with water, and then polished on a revolving lap covered with broadcloth using chromic oxide. This process gave a high polish comparatively free from scratches. The polished specimens, of which only the polished faces were exposed, were then heated on a sand-bath over a battery of three Bunsen burners for nearly an hour after which the surfaces were etched by bringing them to a red heat in the oxidizing blowpipe flame, the latter being passed slowly over the face to be treated. Insufficient drying on the sand-bath caused the polished surfaces to split while being etched.

The etched surfaces thus produced were examined under the microscope, using vertical illumination, when the macroscopic structure and characters were seen to persist. The black splendent coal appears white in vertical illumination, and is structureless. It therefore corresponds to the *Vitrain* [1] of Dr. Marie Stopes. Fine strings and lenticles of duller coal sometimes traverse the Vitrain (Figs. 1 and 5). This duller coal, which shows plant structures of various kinds, has not yet been divided into the *Clarain* and *Durain* of Stopes. The *Fusain* or charcoal bands show in many cases, no recognizable plant remains but are no doubt composed of a heterogeneous collection of plant debris. In other cases, however, regular structures are to be seen (Fig. 8, which is identical with that figured by Seyler [2] and called by him woody tissue). The junctions between the different bands are usually sharply defined (see Figs. 1, 3, and 5), and the general appearance of the structures displayed is very suggestive of the "flow" structures of volcanic rocks rather than those produced by pressure on rocks already consolidated (Figs. 1 and 3), and is identical with those of bituminous coals. Plant forms recognized include exines of macrospores, microspores, portions of woody tissue, parenchymatous cell tissue and portions of stems together with many forms not yet named.

[1] Marie C. Stopes (1919), "The four visible ingredients in banded bituminous coal": *Proc. Royal Society*, Series B, vol. xc, p. 470.

[2] Op. cit., p. 218, fig. 9.

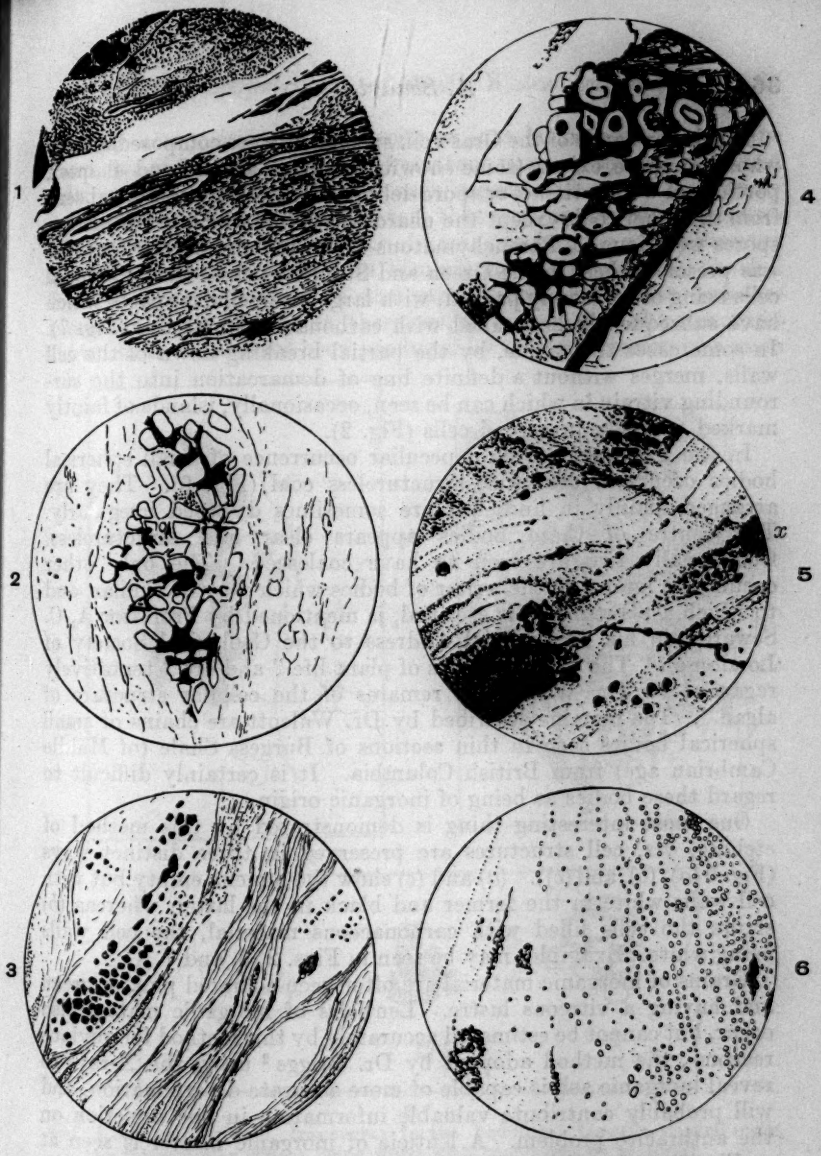


FIG. 1.—Section from Gras Vein, transverse to the bedding, showing sharp junction between structureless Vitrain and duller band composed of exines of macrostores and spore debris.

FIG. 2.—Green Vein, transverse to the bedding, showing lenticle of parenchymatous tissue. Notice the partially broken down cells in Vitrain. × 80.

FIG. 3.—Gras Vein, transverse to the bedding with portions of woody tissue and Vitrain lenticles showing typical "flow" structure. Notice thickening of cell walls in largest piece of woody tissue. × 25.

FIG. 4.—Green Vein, parallel to the bedding showing cells with shrunken contents, possibly due to plasmolysis. × 100.

FIG. 5.—Big Vein, transverse to the bedding showing portion of a lenticle of *Fusain* and a lenticle of mineral matter at *x*. × 25.

FIG. 6.—Pumpquart Vein, transverse to the bedding. × 100. (For description see text.)

The duller bands of the Gras vein specimens were composed almost wholly of spore exines (some showing peculiar arrow-head shapes), portions of woody tissue, or spore debris (Fig. 1). Spores were absent from the other coals except the charcoal vein in which a few macrospores were found. Parenchymatous tissue in long, narrow lenticles was preserved best in the Green and Stanllyd veins, the individual cells being often loosely packed, with large intercellular spaces which have subsequently been filled with carbonaceous material (Fig. 7). In some cases this tissue, by the partial breaking down of the cell walls, merges without a definite line of demarcation into the surrounding vitrain in which can be seen, occasionally, islands of faintly marked partially preserved cells (Fig. 2).

In the Pumpquart vein a peculiar occurrence of small spherical bodies occurs in otherwise structureless coal (Fig. 6). They are arranged mainly in lines but are sometimes disposed irregularly. The centre of these bodies appears clear and structureless. Occasionally two are seen to have coalesced. The only other occurrence known to the writer of bodies which may be similar, and to which a plant origin is ascribed, is mentioned by Professor A. C. Seward [1] in his Presidential Address to the Geological Society of London on " The earlier records of plant life " and are " tentatively regarded by Dr. Walcott as remains of the cellular structure of algae ". The remains described by Dr. Walcott are chains of small spherical bodies seen in thin sections of Burgess Shale (of Middle Cambrian age) from British Columbia. It is certainly difficult to regard these bodies as being of inorganic origin.

One most interesting thing is demonstrated by this method of etching, viz. cell structures are preserved in three distinct ways (Fig. 9 (*a*), (*b*), and (*c*)). (*a*) and (*c*) show the lumena empty but with cell walls white in the former and black in the latter, whereas (*b*) shows the cells filled with carbonaceous material, the cell walls being white. Examples may be seen in Figs. 2, 3, and 7.

Grains of inorganic material are often seen coloured pink or green and having a vitreous lustre. Lenticles of inorganic matter also occur, but cannot be estimated accurately by this method for obvious reasons; the method adopted by Dr. Briggs [2] using the X-rays to reveal inorganic ash is capable of more accurate determination, and will probably contribute valuable information in one direction on the anthracite problem. A lenticle of inorganic matter is seen at *x*, Fig. 5, and grains of inorganic origin are scattered through the coal.

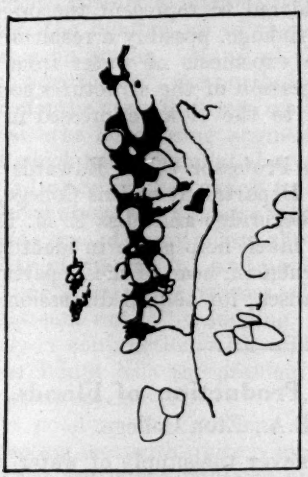
Conclusions.

It would appear from a study of the foregoing that the general characters of bituminous coals are found also in South Wales Anthracite, and that on the whole the same materials have entered

[1] A. C. Seward (1923), " Presidential Address, Geol. Society ": *Q.J.G.S.*, vol. lxxix, 1923, p. lxxxiii.

[2] H. Briggs (1923), *Proc. South Wales Institute of Engineers*, 1923, p. 419.

into the composition of anthracite as into bituminous coals. The character of some of the parenchymatous tissue with loosely packed cells and large inter-cellular spaces suggests plants of a swampy environment. It is noticeable, too, that well-preserved megaspores and cells show no more evidence of having undergone undue pressure than do similar structures in bituminous coals. Indeed, the full rounded forms of most of the parenchymatous tissues seen are remarkable. It is difficult, therefore, to believe that the structures shown in the coal have been produced by the compression of a mass



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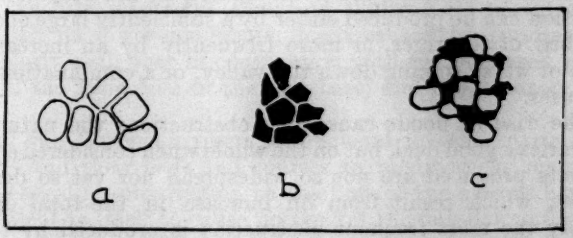

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FIG. 7.—Stanllyd Vein, transverse to the bedding. Loosely packed cells, the intercellular spaces being filled with carbonaceous material.

FIG. 8.—Pumpquart Vein, normal to the bedding. Portion of *Fusain* lenticle showing regular structure. Possibly small squeezed algal-like stems in transverse section.

FIG. 9.—Diagrams showing modes of structure preservation.

of peat or peat-like substance which was many times the present thickness of the coal seam, although this has generally been believed to be the case.[1] Discussion with Dr. A. E. Trueman confirms the opinion that the substance from which the coal was formed may have

[1] P. F. Kendall (1922), Report of the British Association, 1922, pp. 64–5.

been a viscous fluid in which plant remains were being gradually carbonized and their structures were frequently becoming obliterated. The whole mass presumably became more viscous as the process went on, solidification possibly taking place before sufficient time had elapsed for the accumulation of much sedimentary material above it. In such a semi-liquid mass flow structures, such as have been demonstrated, would normally be expected to occur.

The gradual concentration of the material in the waters of the swamp may be indicated by the phenomenon illustrated in Fig. 4; the matter inside the cells is considered to represent the original cell contents in various stages of shrinkage, possibly a result of the process of plasmolysis due to the exosmosis of water from the interior of the cell. If this interpretation of the structures seen is correct, it appears to lend support to the views expressed in the preceding paragraph.

I desire to record my thanks to Professor C. A. Edwards and Mr. H. I. Coe, of the Metallurgical Department of this College, for the use of apparatus; to Dr. F. Mockeridge and Miss E. M. Rees, of the Department of Biology, for much help given in identifying plant structures, and to Dr. A. E. Trueman, head of the Department of Geology, University College, Swansea, for helpful discussion and criticism.

River Drainage and the Production of Floods.

By R. Weatherall, B.A., Eton College.

A RIVER flood is produced whenever the supply of water is in excess of what can be accommodated by the bed alone. Such a condition can be produced either by a sufficiently large obstruction in the bed of the river, or more frequently by an increase in the volume of water coming down the valley, or a combination of these two causes.

In the case of floods caused by obstructions the nature of the cause varies a good deal, but on the whole when considered separately the effects produced are not so widespread nor yet so destructive as those which result from an increase in the total discharge. Probably the most frequent obstruction is produced by the tides, which in some rivers cause daily flooding at all seasons just around the river mouth, but usually only at the fortnightly high tides. Any river draining into the sea through a low mud flat is liable to flood to some small extent under these conditions if the tidal movement is appreciable. Those rivers whose mouths or estuaries are so shaped and situated that floods occur, will flood much more frequently if their banks are sufficiently low.

A second and frequent obstruction, but of lesser importance, is caused by wind blowing contrary to the river current. The head of water held up by wind is always small, so that occurrences are restricted to exposed areas of water. In this way floods are produced

in the low-lying estuary of the Plate River of S. America, and along the shores of Lake Winnipeg in Canada and in other parts of the world where similar conditions obtain. The Runn of Cutch in N.W. India is another good example where water is held up by the N.W. monsoon.

Landslips from the banks are fairly common in some river systems. Obstructions caused by avalanches are of a similar nature except that they are far more ephemeral in their effects. Flows of lava have also been known at times to hold up streams and rivers. Ice produces barriers in various ways. In those rivers which freeze in winter, the holding up of the stream by a jam of floating ice is common in spring. Many of the Asiatic and N. American rivers which flow towards the north flood extensively each spring, because their mouths are still frozen while their higher reaches have already melted—the flood being augmented by the sudden melting of the snow which has accumulated over the winter. Occasionally a glacier may advance from a valley to block up a stream, but the floods produced above the glacier are of no great importance.

In the case of many rivers, the annual growth of weeds reduces the velocity of the stream, and not only do they reduce the discharge, but very often large masses of weed become detached and float downstream until, by lodging, a jam is produced. Such floods, usually in conjunction with other factors, are quite common, and on the White Nile the problem of the "sudd" has been tackled with some success (1).[1]

The ponding back of one stream by another is a type of obstruction met with quite commonly. In the lower part of almost any river floods are liable to occur though this cause. On such rivers as the Nile, where the Blue and White Niles meet, and the Amazon with its lower confluents, floods caused by ponding back occur regularly each year in conjunction with the increased volume of water in the Blue Nile in the first case, and the Amazon in the second.

Many of the European rivers and several in other parts of the world have had their beds and courses so modified by man that, while in general no obstruction to the flow of the stream has been made sufficient in itself to cause floods, yet the liability to flood has often been increased. Docks, embankments, and especially weirs have been built for purposes of commerce, checking the flow of the stream and rendering its grade irregular, so leading to a tendency for the production of local floods, especially between weirs where the fall has in certain cases almost been obliterated. On smaller streams and rivers mill dams and water wheels impede the flow and cause a greater overflow of the banks in times of flood than formerly.

We pass on next to consider those cases in which floods are due to an increase in volume. Since obstructions have been described above, it is convenient first to take instances of obstructions which

[1] Figures in parentheses refer to Bibliography at end of paper.

have been suddenly swept away in whole or in part. The greater number of examples of such floods is associated with ice and snow in mountainous areas, either as avalanches or as glaciers. The quick and sudden melting of the barrier, or its breakdown due to its instability, releases the water which rushes downstream to spread over land where the banks are low. Of a similar nature are the many ways in which temporary lakes associated with glacial action suddenly become drained of water (2). The sudden breaking down of barriers formed of other materials, more especially landslips, may, at times, produce floods, but such occurrences are rare. The bursting of river banks deserves mention, more especially when arising from semi-artificial conditions.

By far the most important way in which floods are caused, considered from the standpoints of frequency of occurrence, lateral extent, and devastation produced, is by a sudden increase in rainfall over part or the whole of the river basin. In this way general or local floods are produced. Here in the first place floods due to heavy downfalls of rain occur at irregular intervals on many of the rivers of temperate climates where cyclonic weather conditions prevail throughout the year; as more especially in Britain and Northern Europe. It is interesting to note that in such downfalls heavy falls of rain occur in a short time, considerably larger than those showers which make up the greater part of the rainy weather of temperate climates. A heavy annual rainfall if well distributed often does not cause flooding; it is the irregularity of rainfall which leads to overflows over the river banks.

In more tropical countries typhoons, hurricanes, and other severe cyclonic storms produce local flooding in much the same manner. If the downfall is quite local then only a small area need be flooded, but cases often arise where local rainfalls occurring at different parts of a river basin are so timed that their water reaches some spot on the main stream all together, when large and devastating floods may be produced.

In general, floods due to heavy rainfall in a short time occur most frequently in those areas where the rainfall is rather low. This may in part be due to the fact that often in such countries most of the rain falls in a few comparatively heavy showers. This tendency for all the rain to fall in sudden relatively heavy downpours reaches its furthest development in the deserts, where very frequently rain only falls at long intervals. As an illustration of this point one may take the climate of Baluchistan and Afghanistan, where flooding produced in this way has given rise to the formation of "dasht" (3). In fact, owing to the absence of a proper drainage system, any moderate downfall of rain in desert regions is likely to produce temporary floods.

Seasonal increases in rainfall are another cause of many and widespread floods. In such instances the time of flooding is quite regular, depending on the climate.

Instances of rivers which flood in this way are far too numerous to mention, but the Blue Nile, Amazon, and Indus, may be given as good examples. It is of interest to note that the seasonal rise in the level of the river may reach considerable dimensions; rises of 40–50 ft. occur even on such large rivers as the Amazon (4), and the Yangtse, while smaller streams may have a dry wady converted into a raging torrent within a few days at the onset of the wet season. An important feature of these floods is that they are more prolonged than those so far dealt with, their duration being determined by that of the wet season, or the wettest part of it, if the rainfall varies much.

The monsoons, being merely a special type of climate showing well marked wet and dry seasons, give rise to floods which are often further aggravated by the melting of the mountain ice. Summer melting of ice and snow produces exactly the same effects as a wet season. Those Siberian and North American rivers which flow towards the North have their spring floods increased by the sudden melting of the ice and snow which has accumulated through the winter months, which, melting all together, produces large quantities of water for a river to deal with whose mouth, being further north, is still frozen. The quagmires which occur on the Russian Steppes temporarily each spring are of similar origin.

The rapid melting of ice in spring due to warm winds like the Chinook of North America only tends to accentuate the river floods at that time of the year.

In the above discussion emphasis has been laid on the more general causes of river flooding, with an attempt to treat each case by itself. If one wishes to study the different ways in which several of these causes react on each other, the Nile, Amazon (4), and Indus are good rivers to choose. The Nile especially has been subjected to thorough investigation (1).

It may be added here parenthetically that a few rivers appear to be partly compensated in their supply of water throughout the year. The Rhine (5) appears to be such a river, where summer melting of ice occurs when the monthly rainfall is at a minimum. The "Mediterranean" type of climate has a typical dry period in summer, and will give similar results, so that one expects the Rhone valley to be little troubled with floods and this is found to be the case. In many instances, too, owing to warmer weather in summer, less of the rain which falls finds its way to the streams in consequence of evaporation. This factor may help to keep a river level fairly constant throughout the year, or it may work in the reverse direction, depending on the seasonal distribution of the rainfall.

In seeking for reasons why flooding occurs at one part of a river's course and not in others, one is confronted with innumerable interacting causes all included in the cycle of denudation and river erosion. Such points as the height of the banks, mean velocity of the water throughout the year, nature of the bed, and nature of the

land bordering the banks, along with many others, can all be brought forward in turn. On analysis, however, all these factors are found to be so closely interdependent that it is unnecessary to isolate individual ones. In general, it can be stated that floods are most likely to occur where the banks are low, the land sloping only at a small angle up from the banks (or actually lying below the water-level of the river in some cases), where the mean velocity of the current is small (closely connected with the slope of the bed), and where natural impediments to a sudden and large acceleration of the current are found, due to the nature of the river bed and its course. A meandering river offers a large resistance to any rapid increase in the river current. A combination of these and similar factors occurs usually only in the lower parts of rivers which have reached an advanced stage in their cycle of erosion. In younger river systems where the bed has not yet cut down to produce a continuous graded course, floods may occur at points where the slope is very small. In this way temporary flood-plains can be established.

Since the early theories in geology were abandoned, sufficient emphasis has not been laid on the great changes which can take place in a river valley, and more particularly in its bed, in a short time during floods. Some of the most striking features produced are that the bed gets scoured out and deepened, and possibly widened, meanders get broken through and the course tends to straighten out; the banks are at such times likely to burst and lead to the production of a new course. On the land adjoining the banks, floods are most remarkable for the damage and loss they cause to human industry, but quite apart from that the effects produced are worthy of consideration. Depending on the situation, times of flood are marked by greatly increased erosion of the whole land surface, especially where the slope is small, while in the flood-plain the slow rise in the level of the land which occurs by the deposition of sediments is due almost entirely to floods. All these effects are due to the greatly increased total energy of a river in times of flood over what it possesses in more normal times. The writer was greatly struck in August, 1922, by the marked changes which had taken place in the bed of a small stream, usually no more than a trickle and often dry in summer, after the exceptionally heavy rains which occurred in the Midlands in the first few days of the month. On 7th August from two to three inches of rain fell in parts of the Midlands in a very few hours, and this stream, which is in the middle of Nottinghamshire, increased many times above its normal volume ; the banks were covered with a swift current of water to a depth of several feet, and in places the whole of the surface soil was washed away to be deposited again in adjoining hollows where the current had slackened.

Apart from the changes produced in the bed of a river, and the land in the near vicinity of the banks, and of those of the main tributaries ; times of flood when due to excessive rainfall or to extensive melting of ice and snow are often associated with striking

changes in the whole land surface of the catchment area. At times like these, landslips and mudflows are most likely to occur, the slow downward creep of the surface soil becomes greatly augmented, and in the case of rain, transport of rock fragments on the surface of the land down to the river bed may become an important feature which is almost entirely absent during light showers when the rain sinks into the soil as it falls, and only finds its way into the streams through percolation.

From the time when land first becomes elevated above sea-level, until it is submerged again below the surface of the water, it must have some sort of drainage system to cope with any water which is precipitated upon it as rain or snow. The *character* of this drainage system, including river bed and discharge at any moment, depends upon a multitude of factors most of which can be grouped under the terms Climate and Topography, but the effect of time is very important. Little importance has so far been attached to the changes which go on from day to day in the character of the river bed, in the fluctuating level of the water, and in the velocity of the stream. In addition to the slow change which depends upon the grand cycle of denudation and river erosion (omitting climatic and other changes) a river system is in a state of continual change ; varying with the conditions prevailing at the time and with those the most recently antecedent. With a little imagination one might say that a river is always trying to adapt itself to the physical conditions prevailing temporarily over the catchment area. This adaptation is far more elastic than is generally believed, but is restricted primarily to the level and volume of the water, and secondly to the river bed, and is only indirectly connected with slow changes in the river valley. Floods therefore are caused when, owing to sudden changes in the water supply, or discharge due to obstructions, the river cannot become adapted quickly enough to deal with the new state of affairs. In other words, while under ordinary quiescent conditions a river bed is adequate to deal with the water coming down from higher levels, times of flood are those when this relationship no longer holds and the drainage between banks becomes inadequate.

Viewed in this light, one might say that a river system is always *tending* to become just adequate for the physical conditions of its basin at the time. Floods really should be always considered as abnormal occurrences, emergencies for which the river is unprepared, and demanding too sudden a change in the nature of the drainage system. Again, floods are only temporary phenomena, and even if the supply of water were kept up for a considerable period, the flood water would continually diminish after the first big rise, owing to changes in the river's bed, while obstructions in general merely hold up water for a time, since by increasing its fall they also increase the energy available for erosion.

The statement that floods occur most frequently in the plain tract of a river's course is so obvious as almost to appear ridiculous, except

after reflection. One must realize that the flood-plain exists as a result of preceding changes which have taken place in the river basin, due to, and having been built up by, the river itself. The resulting position is such that the river is never permanently in flood even in the flood-plain where its bed is often at a higher level than the surrounding land, but the tendency to flood has increased with the age of the river. For the average climatic conditions the river has so adapted itself near its mouth that it is just adequate, but not more, while its elasticity to cope with sudden changes by increased depth and velocity of current has gradually been reduced. As the base level of erosion is approached in the course of time the flood-plain tends to spread up the river to an indefinite amount. In the torrent and valley tracts of a river system the drainage is nearly always adequate, but even there floods may arise under exceptional conditions such as have been outlined above. Here too, the river is continually eroding away its bed, tending towards the production of a peneplain as a final result. Occasionally it happens that after having reached a certain base level of erosion a river system receives an increase in its water supply through some climatic or other change. The main results of such an event are that the higher parts of the river bed become deepened and possibly widened while the velocity increases slightly owing mainly to the removal of obstacles and the straightening out of the course. In the flood plain at first there is an increased liability for floods to occur, but each flood by the deposition of silt raises up the banks and the level of the land. The final result is that in the course of time the river again is quite adequate throughout its length.

There seems to be one marked exception to the generalization that all rivers tend to become just adequate for the conditions prevailing over their basins. These rivers, which being either rain- or glacier-fed run and disappear in the sands of deserts appear to be permanently inadequate in their lower parts. As a consequence, the river may be said to be in a state of permanent flood—supposing conditions to be uniform throughout the year. Actually, of course, these rivers flood at certain times of the year, depending on the seasonal distribution of the rainfall or the melting of ice and snow in the hot season. In such rivers all the sediment brought down from the torrent-tract is deposited in the bed and on the sides of the stream, the bed always receiving its quota first. Although the damming effect of the sediment so deposited helps to increase the head of water, and so the transporting power of the water, the final state is never such that the river is no longer likely to flood except under abnormal conditions.

Not only is there the fluctuating adaptation, as has been shown in the examples given above, but over a period of years a more gradual process is also going on. One or two instances will make the point clearer. Suppose that a delta is being formed at the mouth of a river, it will act as an obstruction to the current by blocking up the

channels and reducing the slope until the river is liable to flood when the volume is increased. Any floods produced in this way tend to raise the general level of the valley and so reduce the chances of further liability to flood under similar conditions. Similarly, a gorge can always deal with the heaviest of floods along a river; but it also indicates youth in the drainage system, and, other changes being ignored, a time will come when the banks will have been denuded down to the flood level of a peneplain. This aspect of changes in drainage systems has received full treatment by most writers on river erosion.

The works of man may be cited as instances of the principle that floods only occur when the drainage system becomes inadequate for the exceptional conditions prevailing at the time. On river systems he builds bridges, weirs, and locks; in others he alters the course and bed, and some he canalizes; and while in each case he makes allowances for expected weather conditions beyond the average, yet circumstances which demand a drainage system of still larger size will result in floods which may be all the more disastrous because of the artificial limits which have been imposed upon the river.

There are extensive areas of the land surface where the greater part of the drainage system is underground. It is rare in such places not to find some indication of a surface drainage system which comes into use during times of heavy rainfall or other similar conditions. Temporary stream and river valleys give quite a characteristic relief to these areas in which the actual line of the stream bed becomes marked out as a dry gully. Taking an extreme case, where the rock is very porous and almost the whole of the rainwater escapes underground, only in times of exceptionally heavy rainfall are the valleys required to remove surface water. Because of the rarity of the occurrence under such conditions, floods are very liable to occur to some extent, forcing themselves upon a drainage system which from the very nature of the case must necessarily be inadequate. The surface of the soil can absorb water almost as fast as it falls in a great many instances; but it is interesting to note that as soon as this limit is passed surface water moves downwards with very marked effects.

Where a larger percentage of the annual rainfall is removed by surface drainage, the conditions in temperate climates approach those of an ordinary river valley, but seeing that the amount of water flowing underground is almost unaltered by the seasons, the main effect of porous strata will be to increase the relative size of the fluctuations in amount of water draining into surface streams. One is led to expect that in such areas floods are more liable to occur than under similar climatic conditions where the rock is not so permeable.

Before closing this account of the adequacy of river drainage one or two points regarding topography as affected by river systems are

worthy of consideration. It is obvious that there is a direct relationship between the climate of any area and its drainage system, as represented by the number of streams of unit size to the square mile. In dry climates one has to go long distances from stream to stream, while in more humid districts every few hundred yards one meets with some tiny rill. Such distribution or concentration of streams per unit of area will leave its mark on the general relief of the whole area. Speaking generally, dry climates are marked out by undulations and hill ranges with relatively broad bases and low ridges; while wetter areas are more deeply cleft into narrower and steeper valley slopes. The distribution of streams, therefore, determines not only the distances between the crests of the hills, but helps to fix the average slope of the land surface towards the valley bottom. The relief of a relatively dry district is cut with more generous curves and slopes—the broad span of the major watersheds being smoother and less frequently cleft by the valleys of small streams. Wetter areas show narrower major ridges deeply serrated by many stream valleys which may themselves be further cleft by the valleys of still smaller streams. This connexion between the relief of a country as determined by its drainage system and the climate breaks down under extreme conditions, such as high altitudes and deserts.

It must be admitted that the relationship between climate and the centralization of streams per unit of area is greatly complicated by many factors such as geology, past history, and seasonal change of weather. Because of this it is not at all easy to compare the topography of similar areas without making numerous reservations. Again, the term " unit size " when applied to a stream does not admit of very exact definition, since " size " can refer either to dimensions or discharge which may or may not be connected together, and each of which varies through the year.

For comparison it seems probable that average discharge through the year would be the best basis on which to make a classification of streams. It will be observed that streams with equal discharges are smaller in wetter districts and hilly country than in drier parts or level plains, but suitable allowance can be made in each case.

Omitting areas of porous rocks and climatic extremes, it will be seen that the relief of the land surface is determined mainly by the smaller streams. The general slopes, the height and frequency of the minor ridges, and the contour of the land surface, are all determined more by the numerous small streams than by the larger rivers into which they flow; which in their turn impress a relief of still greater amplitude upon the whole land surface. The distribution of the larger rivers is often the result of the interaction of many and complicated factors acting over long periods, but that of smaller streams alter more quickly. These latter can be considered as arising as direct results of particular climatic conditions, and their concentration per unit area appears to be little influenced by slope of the land or altitude, except the little bit due to a direct or meandering path.

The number of the smallest streams, however, is very much influenced by the nature of the rock surface they drain, since bare or impermeable rocks encourage the flow of even the smallest surface trickles, while porous soils especially if covered with a dense growth of vegetation, lead to larger streams arising from springs.

In areas of very porous rocks, where the greater part of the drainage is underground, the surface relief is mainly determined by the erosive effects of the remaining superficial drainage system. Since the water removed superficially is in all such cases only part of the annual rainfall, not lost again by evaporation, the general contour of the country approaches that of similar areas of impermeable rocks with drier climates. The undulating down-like effect in limestone countries is a characteristic result of surface erosion under such conditions.

Limestone and other areas of porous rock are also characterized by the number of streams arising from springs. As a consequence of this the number of very small streams to the square mile is usually much reduced and so the ridges dividing the medium-sized stream valleys have a very smooth contour, hardly etched at all by smaller subsidiary valleys.

The effect of the general slope of the land surface towards the sea upon the distribution of the smallest streams has already been referred to. Just slope alone does not appear to have any marked effect upon the concentration of the smallest streams ; its action being usually masked by the nature of the land surface. The general incline of the land is, however, reflected in the course which these streams take, since sharp slopes lead to the production of parallel ridges and valleys, while more gentle ones give rise to winding rivers and isolated rounded eminences. Comparing the concentration of small streams near the source of a large river with that on the flood plain, they differ not so much in number as in the courses they take. Larger streams are much more affected by land slope which materially affects discharge, so that flat areas have more in each square mile than more sharply graded districts. In every case the courses of the smallest streams, whether producing parallel ridges or isolated rounded hills, very closely affect the general topography of the land, not so much in amplitude as in arrangement. Where the general land slope varies considerably within a short distance, as in hilly and mountainous districts, the topography of the land becomes correspondingly complicated both in amplitude and general arrangement, while geology and past history become increasingly important as agents affecting stream distribution.

As one follows the sequence of events in river erosion and the gradual evolution of consequent, subsequent, and subsidiary valleys, it becomes evident that the courses of the smallest streams will be very much altered as time goes on—at least in direction. At first, with a fairly uniform slope, the tendency will be for all to flow in parallel courses, but as subsequent streams develop their valleys

become invaded by the cutting back of larger streams, which in time divert their water into more circuitous routes. If, as is very likely, the slope is sharper further inland than near the river mouth, there will be a greater number of streams of intermediate size in the more level areas than in more hilly districts. Similarly the progress of erosion appears to be accompanied by an increase of the number of these intermediate streams spreading gradually from bottom to top of the main river basin. Erosive action, since it affects the rock surface, alters the absorptive nature of the land, so that other things being equal the land of the flood plain is more porous and retentive of water than that higher up. This last effect exerts a direct influence upon the number of very small streams in the two areas and upon the general land slope and contour.

It seems evident that over a typical river basin, climate and nature of the rock surface very closely affect the concentration of the smallest streams, and the general slope of the land. The results are such that under any given climatic conditions an average fall of rain (or water as melted snow) is removed by the streams in much the same time, which is rather shorter for hilly districts and longer for plain areas. Bare steep hill slopes get rid of their water more quickly than porous undulating plains, but against this one must set the counterbalancing fact that usually the rainfall is heavier in the more hilly districts. While it is not easy to speak of adequacy in respect of general land relief, it appears to the writer that the land surface does reflect very closely the climatic conditions to which it is subjected, so that the final object—the removal of surplus water—is carried out with the same efficiency in all normal cases. Exceptional downfalls of rain will still be likely to cause sudden changes in the whole land surface, but even here their general effect is further to dissect up the land into drainage channels.

The actual slope of the land surface is mainly due to the factors, climate, and nature of the rock. A low annual rainfall, mainly of small showers, and a porous soil, result in gentle undulating slopes. As the rainfall increases the porosity of the rock becomes taxed more and more, until on rainy days superficial flows of water occur over the rock surface. Under such circumstances erosive action is set up, which carves out a more suitable slope for the land, and cuts fresh drainage channels to supplement those already existing. This surface flow of water will be a very potent agent in moulding the general land slope to suit particular climatic conditions, since its effect is in proportion to the water in excess of that retained by the soil and vegetation; so that steep slopes are formed in wet districts while dry porous districts have low rounded hills with easy gradients.

The concentration of small streams per unit area and of the larger ones as well seems well designed to deal with rainfalls as they occur. A low slope reduces the discharge of a stream; so that one finds flat districts with about the same number of the smallest streams as hilly parts, but with more streams of intermediate size per unit area.

It will be observed that exceptional climatic conditions produce effects similar to those which have already been described, both as floods in the valley lateral and surface effects on the land itself. In every case the direction in which such changes progress is such as to make a second similar crisis easier to deal with, a process of adaptation having been initiated which may continue or regress as time and circumstances demand.

From the above observations, it appears that the idea of drainage should not be restricted solely to the river and its bed, but should be expanded to include the whole of the land surface. Since in all cases the function of a drainage system is to remove all water not lost by evaporation; under any given conditions if sufficiently permanent, this object will be achieved. If these conditions vary at all, then corresponding changes are begun in the drainage system, but since these latter will always lag behind climatic changes, in times of sudden excess the system will be found inadequate, and floods may arise. Topographical features in temperate climates are closely bound up with drainage systems, and will change in accordance with climatic changes; but since the total effect is superficial and fairly uniform over the whole area the effects produced are not so obvious. In addition, the erosive power of moving water increases with its volume, so that changes in the river bed are far more rapid than those over the land surface. Adaptation and adequacy of drainage are therefore much more plastic when applied to streams and rivers than to the land itself; but in every case these changes are always going on to fit the particular climatic conditions prevailing at the time.

In conclusion, I should like to thank Mr. B. B. Dickinson for the use of his library, for many useful suggestions, and much valuable criticism.

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See also:—

Neve, "Journeys in the Himalayas and some factors of Himalayan Erosion": *Geog. Jour.*, vol. xxxviii.
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REVIEWS.

THE TINFIELDS OF NASSARAWA AND ILORIN PROVINCES. By C. RAEBURN. Bull. No. 5, Geological Survey of Nigeria. pp. 63, with 7 plates, maps, and plans. Published by the Nigerian Government. 1924. Price 10*s*. net.

THE tinfields described in this Bulletin lie to the south-west of the areas dealt with in earlier publications, mainly south and south-east of Jemaa and adjoining the western margin of the Plateau Tinfields. It is rather difficult for those unacquainted with the country to locate the exact position, since the small index-map provided has no scale, and no indications of latitude and longitude. The general geology consists of an older series of schists, gneisses, and gneissose granites, with numerous pegmatite dykes, apparently later than the main mass of the granites; the whole was later invaded by the younger or Plateau granite, which is likewise believed to be of Archaean age. Basic dykes are also fairly numerous. Tinstone has been introduced at two distinct periods, in the pegmatites and by the younger granites: the last-named occurrence being a result of pneumatolytic action on the surrounding older rocks, with greisen and topaz rocks. In the pegmatites tinstone is clearly a primary mineral. The description of these rocks shows many interesting features. The absence of tourmaline in connexion with the pneumatolysis of the granites and gneisses is noteworthy, while topaz is abundant: this suggests a scarcity of boron and abundance of fluorine in the magma. It may be remarked that some of the micro-photographs reproduced as plates are particularly good.

PALÆONTOGRAPHICAL SOCIETY. Vol. LXXV. Issued for 1921. London: December, 1923.

THE volume of the Palæontographical Society's Monographs for 1921 has at last made its appearance; it is dated December, 1923, but seems not to have been distributed to members of the Society until February, 1924. The volume contains another part of the late F. W. Harmer's "Pliocene Mollusca of Great Britain" and the first part of Dr. L. F. Spath's "Monograph of the Ammonoidea of the Gault". In a brief Introduction Dr. Spath makes some general statements on phylogeny. He regards the Gault Ammonites as derived from two parent stocks, the Phylloceratidæ and the Lytoceratidæ, and he believes the "families" Desmoceratidæ and Hoplitidæ to be polyphyletic. The author quotes from J. F. Blake the remark "that the indiscriminate giving of new names for Cephalopoda was the work, not of palæontologists, but of nomenclaturists". We note, however, that Dr. Spath introduces many new generic and family names without giving diagnoses: possibly later writers may look on this as "indiscriminate".

Dr. Spath regards *Bactrites* as a secondarily uncoiled goniatite, and *Barrandeoceras* as the ancestor of the Ammonoids. Evidence in favour of these and other statements would be welcome; and as the author speaks of "the customary laws of ammonite development as two-edged swords", it is to be hoped that in a later part of the Monograph he will explain the principles on which his phylogenetic work is based.

The Secretary of the Palæontographical Society is Sir Arthur Smith Woodward, Hill Place, Haywards Heath, Sussex.

GUIDE TO RHODESIA for the use of Tourists and Settlers. pp. 431, with illustrations, maps, and plans. Second and revised edition. Issued by authority of the Beira and Rhodesia Railways. London Office: 2 London Wall Buildings, E.C. 2. Publishers for South and Central Africa: Davis & Co., Bulawayo. Price 2*s.* 6*d.* net.

TO the intending traveller who has not yet made up his mind where to go, we doubt whether there is any undeveloped country surpassing Rhodesia in interest, whilst to the scientist and the antiquarian it represents an unexploited mine of untold possibilities. In the volume before us, the geology, archaeology, and history of the colony are dealt with in a manner calculated to make the reader desire to know more, whilst there are also chapters on sport, farming, and other matters. There are four maps, one hundred and eighty-three illustrations, and an excellent but somewhat incomplete bibliography.

REPORTS AND PROCEEDINGS.

GEOLOGISTS' ASSOCIATION.

Friday, 2nd May, 1924.

"The Faunal Relations of the Crag Deposits of the Bentley District, Suffolk." By Professor P. G. H. Boswell, O.B.E., M.I.M.M., D.Sc., F.G.S.

The molluscan fauna of the deposits of Red Crag in the neighbourhood of Bentley, between the estuaries of the Stour and Orwell, is considered in detail. As compared with other Crag localities, the faunal list is not large (about 130 species); nevertheless, many interesting forms occur, and the investigation indicates that much work remains to be done at other Crag localities. About 55 species are characteristic of the Waltonian or older Red Crag, but many of the shells are derived. Only a few boreal species, characteristic of the latest or Butleyan Red Crag, have been found. The deposits may best be referred to the middle or Newbournian Red Crag, and indicate a northward withdrawal of the Crag Sea, accompanied by erosion of the upraised Waltonian Crag on the south.

"The Petrography of the Later Tertiary Deposits of the East of England." By I. S. Double, F.G.S.

The deposits described are the Pliocene, which occupy the eastern parts of Norfolk, Suffolk, and Essex. The subdivisions include the Basement-bed, Coralline Crag, Red Crag, Norwich Crag, Chillesford Beds, Weybourn Crag, Cromer Forest Bed, and *Leda myalis* Bed. The Arctic Freshwater Bed, though usually placed in the Pleistocene, is found to have petrographical affinities with the Pliocene. The assemblage of detrital minerals is found to comprise garnet, magnetite, spinel, anatase, rutile, zircon, apatite, ilmenite, quartz, tourmaline, andalusite, biotite, brookite, chiastolite, sillimanite, staurolite, topaz, marcasite (or pyrite), actinolite, chlorite, epidote, common hornblende, muscovite, orthoclase, sphene, tremolite, albite, anorthoclase, kyanite, microcline, and oligoclase. The distinguishing feature of the assemblage is the constant association of large crystals of red and colourless garnet, green tourmaline, andalusite (and chiastolite), staurolite, kyanite, white mica, and green hornblende. The coarser constituents include the "boxstones", flints, quartz-pebbles, quartzites, sarsenstones, Hertfordshire conglomerate, Greensand chert, London Clay septaria, bedded sandstone fragments of doubtful age, rotted boulders of Kellaways Rock, *Rhaxella* chert, various igneous rocks, and derived fossils. Comparison with the mineral constitution of earlier British sediments shows that the probable source of the finer material lay outside Britain, possibly in the metamorphic rocks of the Ardennes, whilst the coarser constituents were probably ice-borne from the north or north-west. Certain palaeogeographical results which flow from the investigation are considered.

Yorkshire Geological Society.

5*th April*, 1924.

"The Beds Underlying the Magnesian Limestone." By H. C. Versey, M.Sc., F.G.S.

These beds, the "Yellow Sands" of Lebour and the "Quicksands" of Sedgwick, occur in a number of isolated outcrops at intervals along the Magnesian Limestone escarpment. These outcrops, together with the boring records in the concealed coalfield, show that the sands are arranged in parallel areas trending E.S.E. and separated by areas where no sands occur. Towards the eastern end of these belts the sands give place to black shale with *Lingula credneri*. The general absence of littoral deposits at the base of the limestone points to the land area having been reduced almost to base-level conditions. The advance of the Zechstein strand-line was not uniform all over the area because in the area between Ripon and Doncaster the basal beds with *Productus horridus* are overlapped.

The rock-fragments in the sands include sandstone, chert,

quartzite, mudstones, and pegmatites, all pointing to a Carboniferous source. This is confirmed by the heavy mineral assemblage, which includes almandine, rutile, tourmaline, zircon, ilmenite, magnetite, fluorspar, barytes, staurolite, apatite, monazite; three varieties of barytes are noted, authigenous crystals, allothigenous fragments showing good cleavage, and rounded detrital grains identified chemically. Staurolite points to a Coal Measure origin. All the minerals show evidence of a second cycle of erosion, and the distribution of apatite is confined to the more cemented layers.

The sands are invariably rounded, and elutriation experiments show a marked uniformity in grade size. Field sections show evidence of redistribution in water accompanied by kaolinization of felspars, but in special areas true æolian current-bedding is visible. These observations, together with the restricted distribution in belts, suggest comparison with the river valley dunes described from S.E. Russia and Turkestan.

The occurrence at Brearton, near Knaresboro, showed, in the author's opinion, a mineralogical assemblage different from any seen by him in Permian rocks in Yorkshire. He considered that it was separated from the Magnesian Limestone by a continuation of the High Hutton Fault and that it could probably be paralleled in some of the Triassic sandstones which are similarly mottled.

Liverpool Geological Society.

8th April, 1924.

The following paper was read :—

"Notes on the Petrology of Penmaenmawr Mountain." By H. C. Sargent, F.G.S.

The outcrop of the intrusion of Penmaenmawr forms an irregular oval area $1\frac{3}{8}$ miles in length, and nearly one mile in width at its widest part. It rises to a height of 1,550 ft. from the shore of the coast of Carnarvonshire.

In this paper the differentiation of the mass is traced from base to summit, and laterally to the margin. Plagioclase, enstatite, and augite are the essential minerals occurring throughout. Quartz and orthoclase are abundant above 1,100 feet above O.D., biotite from the base up to about 1,200 feet, and hornblende in the uppermost rock of the eastern shoulder of the mountain, known as Graig Lwyd.

Felspar occurs in three generations, phenocrysts, laths, and allotriomorphic material. Enstatite occurs in two generations ; (1) phenocrysts, nearly always bent and broken, and averaging about 1·8 mm. in length. These range from base to summit and are assumed to belong to a pre-intrusion phase of crystallization. (2) small crystals averaging 0·2 mm. in length. These are not found on the higher horizons.

Below 1,000 feet above O.D. the rock is a remarkably fresh

enstatite porphyrite. Above that level turbidity of felspars and serpentinization of enstatite, with production of epidote and prehnite, set in, and quartz and orthoclase, mainly in micrographic intergrowth, come on abundantly. Plagioclase, which is labradorite lower down, becomes less calcic upwards till the composition of oligoclase is attained. These changes are ascribed to the straining off of the residual liquid, containing the lighter siliceous and alkaline constituents, after crystallization of the minerals with highest melting points, calcic plagioclase and magnesian pyroxene.

The alteration of felspar and enstatite, with production of secondary minerals, on the higher horizons is ascribed, not to atmospheric agencies, as has been assumed by previous writers, but to reactions between the crystals and the volatile constituents in the residual liquid. The production of hornblende on the higher horizons of the Craig Lwyd area is ascribed to increased concentration of volatile constituents.

The marginal rock is an andesitic porphyrite constituting a chilled-border phase. On the extreme eastern margin this rock merges into a thin bed of a much altered, spongy felsite.

OBITUARY.

Sir Jethro Justinian Harris Teall.

BORN 5TH JANUARY, 1849. DIED 2ND JULY, 1924.

All geologists will have heard with sorrow of the death of Sir Jethro Teall, who has been prominent among them for half a century, his first geological publication dating from 1875.

A general account of his life and work appeared in this Magazine in 1909 (GEOL. MAG., Dec. V, Vol. VI, p.1), accompanied by an excellent portrait. As most of his work had been accomplished at the time when that account was written, and is noticed therein, it will not be necessary here to allude at length to his official work on the Geological Survey or to his geological writings which, indeed, remain as a monument to his genius, and must always be consulted by the student of petrology. An endeavour will be made to present, however inadequately, some idea of the personality of the man who was so beloved and respected by his contemporaries.

Before doing this, however, some mention should be made of the general nature of his geological work. In the years 1883–4, three papers of paramount importance appeared, the results of long and laborious investigation. They deal with the Cheviot andesites and porphyrites, some north of England dykes, and the chemical and microscopical characters of the Whin Sill. Before their appearance petrographical work in this country had been mainly descriptive, and confined chiefly to macroscopic and microscopic description of rocks, but Teall introduced new methods into Britain, showing the importance of chemical investigation, and laying the foundation of the study of the genesis of igneous rocks.

In 1885 he began his investigation of metamorphic rocks with a study of certain Highland dolerites converted into hornblende-schists, and in later years added largely to our knowledge of these rocks in publications dealing with those of the Lizard peninsula, and especially of the Scottish Highlands which appeared largely, though not entirely, in various memoirs of the Geological Survey.

In the case of the metamorphic as of the igneous rocks, he initiated lines of study which have proved most fruitful.

In 1888 appeared his great work on *British Petrography*, no mere textbook, but full of original matter. The book is so well known that it would be unnecessary to allude to it, save to mention the great assistance he received from his ever helpful wife in the preparation of the beautiful plates.

Though Sir Jethro's writings were mainly petrographical, he always followed with interest the progress of other branches of the science, and also of other sciences, and his face was familiar at many a scientific gathering.

Let us pass from the work to the man himself.

He was tall and well-built with a head and face which at once arrested attention, as may be gathered from a study of the portrait to which allusion has been made. A well-cut face was in early days framed in raven hair and full beard, and the large dark glowing eyes were wont to produce a feeling of awe in candidates who presented themselves for an oral examination, but the candidates were at once put at ease by the charm of Teall's manner, which was unvarying when addressing all sorts and conditions of men. It may be here remarked that he was an ideal examiner.

In his writings he exercised great caution. When he turned his attention to petrology, he published little for several years before the appearance of the three papers to which allusion has been made, and was always averse to hasty publication. The value of his work is no doubt much enhanced by this cautious attitude.

As a speaker the same attitude was maintained. He spoke simply, with no striving after rhetorical effect, but always clearly and concisely. This was the case whether joining in a discussion or giving a paper or lecture. As a teacher he would have been most successful, but his opportunities in this direction were few after leaving University College, Nottingham, and one feels that a career as a teacher would have been less attractive to him than that which he ultimately chose.

He was at all times a delightful companion, never more so than in the study over an after-dinner pipe, and in the field. His conversation ranged from grave to gay, from trivial matters to abstruse subjects, marked always by a delicate humour, and interrupted often by his hearty laugh. His kindliness and courtesy, the absence of dogmatism and of signs of impatience, his eagerness and energy, all shone forth on such occasions.

His honesty and uprightness were transparent to all, and he was

universally trusted. When he was Director of the Geological Survey the staff placed complete confidence in his judgment; but, indeed, we may say that of all who had dealings with him. Had advice to be sought, often in delicate matters, or if a conciliator were needed in case of disputes, men naturally turned to Teall, and never in vain. Honest and high-minded as he was himself, he was ever lenient to the shortcomings of others, and seemed to assume that they must be as good as himself.

Sedgwick (whose lectures Teall attended when at Cambridge) once remarked, "I have never had a geological secret in my life," and Teall might have made the same remark. He imparted his knowledge freely, and the amount of information which was thus conveyed has undoubtedly contributed in a high degree to the production of much valuable original work by others.

Such, and much more, was Sir Jethro Teall. A beautiful life is ended, but its effects will be long felt for good in the future.

J. E. M.

CORRESPONDENCE.

THE NOMENCLATURE OF ROCKS.

Sir,—Will you kindly allow me space to urge on Mr. Wells the importance of the maxim "verify your references". The title of my paper on the Derbyshire lavas was not, as quoted by him in the current number of the Geological Magazine, "Lower Carb. Spilites in Derbyshire." It was "On a Spilitic Facies of Lower Carboniferous Lava-Flows in Derbyshire"—a distinction with a considerable difference. It is, moreover, incorrect and misleading to quote me as having named the Derbyshire rocks "spilites", without a qualifying prefix.

I have nothing to add to my letter which appeared in your pages in the issue for March, 1923.

H. C. Sargent.

15th July, 1924.